THE EFFECT OF REPEENING AND REPEENING UPON PARTIALLY FATTIGUED COMPONENTS

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Industrial Summary

This investigation examines the respective effects of peening and re-peening upon the fatigue life of partially fattigued and subsequently peened cylindrical vanier of mild carbon steel En8. Room temperature rotating bending tests conducted on initially peened and subsequently peened specimens, at various stages of their estimated fatigue life, generally revealed a substantial life improvement. This improvement is governed however, amongst other factors, by the depth of cracks measured prior to peening. Tests on previously peened partially fattigued and subsequently re-peened specimens indicated complete life recovery, even when the specimen had been partially fattigued by as much as 75% of their estimated fatigue life.

Detailed analysis of the results reveals that the recovery of the fatigue life of previous peened partially fattigued components is due mainly to the strengthening of the "faded" residual stresses in the compressed layer and to the improved peening coverage.

Notation

- $M$: Total fatigue life of a peened specimen
- $M_i$: Initiation fatigue life of a peened specimen
- $M_p$: Total propagation fatigue life of a peened specimen
- $N$: Total fatigue life of an un-peened specimen
- $N_p$: Total propagation fatigue life of an un-peened specimen
- $R$: Stress ratio ($R_{min}/R_{max}$)
- $W$: Chosen loading weight
- $R$: Tensile stress
- $R_{sp}$: Endurance limit for peened specimens
- $R_{sp}$: Residual stress distribution
- $R_{sp}$: Initial lower yield stress
- $R_{sp}$: Upper yield stress

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1. Introduction

The problems associated with the behaviour of metals under repeated stresses are becoming more acute with the increasing demand for energy and weight savings, and the increase in the operational demands of machinery. Justification for the study of compressive stresses, and the processes which induce them, lies in the fact that compressive surface stresses have been found to be very useful in combating fatigue failure. Shot-peening is one of these processes: it uses a high velocity stream of hard spherical particles - such as cast-steel shot - to hammer the surface of a component, thus causing the surface regions to deform plastically. The objective is to impart compressive residual stresses in the surface regions large enough in magnitude to suppress the initiation and the subsequent growth of surface cracks. This is believed to be the basic mechanism of fatigue life improvement due to peening.

Several investigators [1–3] have demonstrated that these residual stresses are not permanent, but tend to fade with cyclic loading. Such a phenomenon was found to be greater at the surface than in the sub-surface layers, and due to high loads rather than low loads [1]. It is reasonable, therefore, to assume that this fading is attributable to the microscopic plastic deformation which takes place during the crack-initiation period and the early stages of growth. Other causes which might result in residual stress fade-out or even complete annihilation include: exposure to elevated temperatures; over-stressing; hostile environments; physical removal of the compressed layer by machining, wear, erosion or surface scratching; and finally through permanent distortion. These causes are indicative of the limitations imposed upon successful peening, unless some means is found to restore the faded-out compressive residual stresses. This can be achieved by re-peening the component. As far as the authors are aware, no attempt has been made to study the respective effects of peening and re-peening upon the fatigue life improvement of partially fatigued un-peened and previously-peened components, and for this reason the present investigation was undertaken.

Two aspects of the material behaviour are examined: (i) the response of
partially-fatigued components to peening treatment, and (ii) the response of partially-fatigued previously-peened components to similar re-peening treatment. In particular, it was desired to determine whether the cyclically faded-out residual stresses of previously peened components can be restored by the re-peening treatment.

For this purpose, room temperature rotating-bending fatigue tests were conducted on cylindrical V-notched un-peened, peened and re-peened specimens made of annealed medium carbon steel (En8).

2. Experimental analysis

2.1 Equipment and specimens

The experimental programme conducted utilised a rotating-bending fatigue-testing machine, and a direct-pressure air-blast peening system. A photograph of the fatigue-testing machine is presented as Fig. 1. One end of the machine is driven by a 3-phase, 7.5 HP (2.24 kW) induction motor operating at a constant speed of 3980 rev/min. The uniform bending moment acting on the specimen was generated by loading equal weights onto two pans attached to respective loading arms. This testing machine is equipped

![Photograph of fatigue-testing machine.](image-url)
with an automatic cut-out circuit, a digital revolution counter and a remote emergency shut-down facility. Linear (and torsional) strain-gauge bridges were installed on one of the flexure shafts and these, in turn, were connected to a series of slip rings, brushes and signal pick-up points, as depicted in Fig. 2. Adequate slip rings were also made available for picking-up the signals from strain-gauged specimens during the initial calibration of the testing machine.

The fatigue machine was initially calibrated by strain-gauging one of the specimens and both static and dynamic calibrations were carried out. During the dynamic calibration use was made of an oscilloscope, not only to measure the magnitudes of the resulting bending stresses, but also to monitor the wave-form during testing.

The shot-peening system used in the present investigation is fully described in ref. 4. The shot-size used was mainly determined by the root radius of the notch and the surface conditions of the specimen. The “MIL-S-13166E” specification* on shot-peening recommends the use of a shot-diameter which is less than half of the notch root-radius to be peened. The

*U.S. Military specification
specification also recommends the use of peening intensities between 0.012 and 0.016 A (Almen Intensity) for mild steel having a minimum section diameter of 15 mm. It was therefore decided to use the following parameters for all the peening and the re-peening treatments: shot size = S170, peening intensity = 0.014 A, nozzle stand-off distance = 152 mm, and jet obliquity = 90°. Full coverage of the specimen was assumed to be 98%.

Preliminary experiments were conducted on the steel investigated (En8) in order to determine the specimen dimensions. The design requirement of the notch and overall dimensions of the specimens were dictated by the need to ensure (i) elastic loading conditions, (ii) rigidity during dynamic loading, (iii) that no distortions resulted from the peening treatment, and (iv) that the number of grains existing across the reduced section was sufficient, so that the experimentally determined properties were representative of a polycrystalline material behaviour. As a compromise, it was decided to choose the dimensions given in Fig. 3 for the steel specimens, the composition of which is given in Table 1. In order to minimize experimental scatter and ensure repeatability, a complete manual of the manufacturing procedure was laid down, and the guidelines given in refs. [5] and [6] were followed wherever possible.

Prior to testing, the specimens were annealed for 90 min at 850°C in a vacuum furnace and then furnace cooled. In order to quantify the mechan-

| TABLE 1 |
|-----------------|--------|--------|--------|--------|--------|--------|
| Element | C | Si | Mn | S | P | Fe |
| Percentage (wt) | 0.43 | 0.26 | 0.78 | 0.033 | 0.028 | rem. |
cal and microstructure properties of the resulting specimens, a comprehen-
sive test programme was undertaken, the details of which are given in ref. [4].
The microstructure studies revealed that there exist no directionality effects
in the grain structure. The average grain-size of the specimen was found to
be 20 μm giving about 760 grains across the reduced section of the specimen.
The mechanical properties of the specimens which are listed in Table 2 were
the averages of five tests. Finally, the hardness measurements indicated a
random distribution of values across the face of the specimens examined.
The overall mean value of hardness was Hv 194 using an indenter load of
30 kgf (294 N).

**TABLE 2**

<table>
<thead>
<tr>
<th>Material</th>
<th>Lower Yield Stress, $\sigma_y$ (MPa)</th>
<th>Upper Yield Stress, $\sigma_{yu}$ (MPa)</th>
<th>Ultimate Tensile Strength, $\sigma_{ut}$ (MPa)</th>
<th>Elongation At Fracture (%)</th>
<th>Hardness (Hv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium Carbon Steel (En8)</td>
<td>411</td>
<td>422</td>
<td>660</td>
<td>29</td>
<td>194</td>
</tr>
</tbody>
</table>

The crack detection and measuring equipment used was the "Crack Micro
Gauge — Type U7G 300 Series" (a.c. field measuring) together with a 10 mm
probe. It is worth noting that the smallest crack depth measurable using this
equipment is 0.03 mm and the largest depth is 45 mm. Post-mortem examina-
tions were carried out to ensure that the actual crack depths were in agreement
with those as measured by the above equipment.

2.2 Experimental programme

The experimental work consisted of preliminary and main test program-
mes. The preliminary tests involved the determination of the $\sigma_a-N$ curves
for peened and un-peened "virgin" specimens with the aim of establishing
the improvement in the fatigue life due to peening for varying applied alter-
nating stress, $\sigma_a$, and to establish the appropriate test load for the main
tests. The test requirements of the appropriate fatigue load were dictated by
the need to ensure: (i) elastic loading conditions, thus ensuring high cycle
fatigue testing; (ii) avoidance of endurance (or fatigue) limit; and (iii) appro-
priate testing time. As a compromise, it was decided to choose a test load of
170 N.

The main test programme comprised two sections. In the first, virgin
specimens were partially fatigued to 25%, 50% and 75% of their mean
un-peened fatigue life $N$ (which could be estimated from $\sigma_a-N$ curves de-
derived from the preliminary test results at the chosen value of $\sigma_a$). The initial
crack depths of these partially fatigued specimens were measured using the a.c. field crack-measuring equipment, described earlier. The specimens were then peened, according to the previously specified conditions, and re-tested to fracture. The fatigue life thus obtained was compared with $N$ and $M$, where $M$ is their mean peened fatigue life. In the second, previously peened specimens were partially fatigued to 25%, 50% and 75% of $M$. The specimens were then re-peened using the same conditions — thus ensuring the same coverage and intensity — and re-tested to failure. Again the fatigue life was compared with $N$ and $M$.

3. Results and discussion

3.1 Preliminary tests

Figure 4 shows the $\sigma_{\text{a}}-N$ curves for peened and un-peened specimens. It appears from these curves that the number of cycles which corresponds to the appropriate test load of 170 N for peened and un-peened specimens is approximately $M = 4.8 \times 10^5$ cycles and $N = 1.5 \times 10^5$ cycles, which is equivalent to 160 min and 50 min of testing time, respectively.

At this chosen test load, the fatigue life achieved by the peened specimens is 333% of that achieved by the un-peened specimens, i.e. an improvement of 233%. This improvement is considered modest, and is attributed to the high alternating stress, $\sigma_{\text{a}}$, used. Another contributing factor is the use of reversed bending with $R = -1$: the residual stress pattern tends to fade out...
with increasing number of cycles [7]. Finally, the use of normalised specimens which are relatively soft and of low strength could also contribute to this modest improvement [8].

The $\sigma_a-N$ curves also indicate that the improvement in the fatigue life could still be achieved even for an alternating stress, $\sigma_a$, exceeding the initial yield stress of the material, $\sigma_y$. This could be explained by the fact that the compressed layer, which is work-hardened by peening, attains a new, higher, yield value.

3.2 Main tests

**Effect of peening upon partially fatigued un-peened specimens**

The results obtained from these tests are summarized in Table 3. The crack readings given in Column (e) represent the mean of the crack depth measurements taken at four different positions 90° apart around the notch. Post-mortem examinations were also carried out to ensure that the cracks were central, and that their depths were in agreement with those as measured using the a.c. field measuring equipment. The results were very satisfactory and in agreement to within 3%.

Despite the statistically intensive crack readings taken during this study, the results show some scatter in the initial crack depth measurements of partially fatigued specimens. However, if the mean of the crack depth of the four different specimens for each experimental group was taken into account, the following results were obtained: mean crack depth = 0.145 mm for 25% N, 0.335 mm for 50% N and 0.683 mm for 75% N, thus indicating a consistent crack growth as the fatigue lives of the test specimens were expended (see Column (d) of Table 4). The standard deviation of the readings was admittedly still high; a larger test sample could probably yield a smaller deviation.

Closer study of the initial crack depth prior to peening and the corresponding fatigue life obtained after peening (Column (d) of Table 4) reveals good correlation between these two, regardless of the pre-fatigue conditions. Figure 5 shows a rapid decrease in the available fatigue life with the increased depth of cracks prior to peening. Hence, it can be deduced that the fatigue life improvement achievable by peening depends to a large extent upon the crack depth existing prior to peening.

Figure 5 also indicates that if the specimen has no detectable engineering cracks (i.e. <0.03 mm) the fatigue life obtained is equal to about 160 min, which is almost equal to the mean fatigue life of a specimen peened when "new". In other words, the partially fatigued material behaves as though it has never been subjected to cyclic loading. This implies that if a component is run for part of its fatigue life, peening of such components yields a much better overall fatigue life improvement than peening while new, the gain being the partial fatigue life already accrued by the component at the time of peening. This can be explained as follows. The bombardment of high
The crack depth around the notch, as measured during this study, is very satisfactory, thus indicating that the cracks in those specimens were exclusively in the crack depth of the readings taken into account. The measurement of crack depth of the specimens was made according to Table 4, which reveals the fatigue conditions of the specimens. The fatigue lives of the specimens were estimated using Table 3, where the crack depth of the specimens was measured around the notch. The specimens were considered as new, that is, the fatigue lives of the specimens exceeded the initial fatigue lives. The results are shown in Table 3.

### Table 3

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Running Time Prior to Peening (Min)</th>
<th>Expected Remaining Life Prior To Peening (N-(b)) (Min)</th>
<th>Specimen Number</th>
<th>Crack Depth Prior to Peening (mm)</th>
<th>Fatigue Life Obtained After Peening (Hrs:mins:secs)</th>
<th>Total Life Since (N) (Hrs:mins:secs)</th>
<th>Improvement Over Remaining Life ((f)-(c)) (\times 100%)</th>
<th>Overall Improvement Over (N) ((g)-(N)) (\times 100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>(b)</td>
<td>(c)</td>
<td>(d)</td>
<td>(e)</td>
<td>(f)</td>
<td>(g)</td>
<td>(h)</td>
<td>(i)</td>
</tr>
<tr>
<td>1</td>
<td>12.5 (25% (N))</td>
<td>37.5 (75% (N))</td>
<td>4.14</td>
<td>0.00</td>
<td>[2:00:49]</td>
<td>[3:03:19]</td>
<td>356</td>
<td>267</td>
</tr>
<tr>
<td>2</td>
<td>25.0 (50% (N))</td>
<td>25.0 (50% (N))</td>
<td>6.09</td>
<td>0.13</td>
<td>[2:30:14]</td>
<td>[2:56:14]</td>
<td>505</td>
<td>252</td>
</tr>
<tr>
<td>3</td>
<td>37.5 (75% (N))</td>
<td>12.5 (25% (N))</td>
<td>4.02</td>
<td>0.35</td>
<td>[1:55:43]</td>
<td>[2:33:13]</td>
<td>826</td>
<td>206</td>
</tr>
</tbody>
</table>

\(a\) \(N\) = 50 min.

\(b\) Specimen accidentally overloaded — data rejected.
## TABLE 4

Mean values of fatigue-life improvement of partially-fatigued un-peened specimens. All mean-life calculations assume log-normal distribution.

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Running Time Prior to Peening (Min)</th>
<th>Expected Remaining Life Prior to Peening (N - (b)) (Min)</th>
<th>Mean Crack Depth Prior To Peening (mm)</th>
<th>Mean Fatigue Life Obtained After Peening (Hrs:Mins:Secs)</th>
<th>Total Mean Life Since New (b) + (e) (Hrs:Mins:Secs)</th>
<th>Improvement Over Remaining Life (\frac{(e)-(c)}{(c)} \times 100%)</th>
<th>Overall Improvement Over (N) (\frac{(f)-N}{N} \times 100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>(b)</td>
<td>(c)</td>
<td>(d)</td>
<td>(e)</td>
<td>(f)</td>
<td>(g)</td>
<td>(h)</td>
</tr>
<tr>
<td>0</td>
<td>0 (0% (N))</td>
<td>50 (100% (N))</td>
<td>—</td>
<td>2:42:12</td>
<td>2:42:12</td>
<td>224</td>
<td>224</td>
</tr>
<tr>
<td>1</td>
<td>12.5 (25% (N))</td>
<td>37.5 (75% (N))</td>
<td>0.145</td>
<td>2:33:33</td>
<td>2:46:03</td>
<td>309</td>
<td>232</td>
</tr>
<tr>
<td>2</td>
<td>25.0 (50% (N))</td>
<td>25.0 (50% (N))</td>
<td>0.335</td>
<td>2:12:03</td>
<td>2:37:03</td>
<td>428</td>
<td>214</td>
</tr>
<tr>
<td>3</td>
<td>37.5 (75% (N))</td>
<td>12.5 (25% (N))</td>
<td>0.683</td>
<td>1:50:27</td>
<td>2:27:57</td>
<td>594</td>
<td>148</td>
</tr>
</tbody>
</table>

\(aN = 50\) min.
Fig. 5. Relationship between crack depth prior to peening and fatigue life available after peening.

Velocity shots onto the exposed surface regions causes a finite layer of the surface to be plastically deformed, which upon unloading introduces a compressive residual stress system at the top layers. If all the initiation sites are obliterated or at least disrupted by the peening action, the entire initiation and early-stage propagation has to be restarted all over again, hence accounting for this improvement in the fatigue life of such components.

Alternatively, if an engineering crack has already been formed at the time of in-service peening, it is unlikely that the crack can be obliterated by the peening action. Assuming that the crack depth is still small, i.e., well within the depth of the compressed layer, this crack will be engulfed in a compressive residual field. The effect of this on the rate of growth depends to a large extent upon the resultant state of stress at the crack region. Figure 6 shows a gradual decline in the fatigue-life improvement as the peening of the par-
tially fatigued specimens is performed progressively later in their lives. It is believed that as the cracks grow deeper into the specimen, the peening treatment becomes less effective.

**Effect of re-peening upon partially-fatigued previously-peened specimens**

Peened specimens were tested for part of their estimated fatigue lives \( M \), and then re-peened and re-tested to complete fracture: the results obtained are given in Table 5. It is worth noting that the fatigue life quoted after re-peening does not include that part of the life which has already been accrued by the specimen at the time of re-peening.

Attempts were made to measure the crack depth of the specimens before and after they had been partially fatigued but the readings obtained were found to be inconsistent: this is probably due to the poor probe-tip contact with the somewhat rough and irregular peened surfaces.

Results of Table 5 indicate a tremendous improvement in the fatigue lives of peened specimens after they had been partially fatigued to 25%, 50% and 75% of \( M \), and then re-peened using the same peening treatment. For all cases considered, complete rejuvenation has been accomplished, even in cases where the specimens were partially fatigued to 75% \( M \).

The following model is proposed to explain the recovery of the fatigue life of a previously-peened partially fatigued component. In this model, shown schematically in Fig. 7, it is assumed that the initial fatigue life of a component is \( N \) and that upon initial peening it becomes \( M \), where \( M \gg N \).
TABLE 5

Fatigue lives of re-peened specimens after being partially fatigued to 25%, 50% and 75% M

<table>
<thead>
<tr>
<th>Identifier</th>
<th>Running Time Prior To Re-Peening (Min)</th>
<th>Expected Remaining Life Prior To Re-Peening (Min)</th>
<th>Fatigue Life Obtained After Re-Peening (Hrs:Mins:Secs)</th>
<th>Mean Fatigue Life Obtained After Re-Peening (Min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>(b)</td>
<td>(c)</td>
<td>(d)</td>
<td>(e)</td>
</tr>
<tr>
<td>1</td>
<td>40</td>
<td>120</td>
<td>4:03:11</td>
<td>218</td>
</tr>
<tr>
<td></td>
<td>(25% M)</td>
<td>(75% M)</td>
<td>3:40:27</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3:12:15</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>80</td>
<td>80</td>
<td>3:50:27</td>
<td>205</td>
</tr>
<tr>
<td></td>
<td>(50% M)</td>
<td>(50% M)</td>
<td>3:12:51</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3:05:42</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>120</td>
<td>40</td>
<td>4:20:15</td>
<td>224</td>
</tr>
<tr>
<td></td>
<td>(75% M)</td>
<td>(25% M)</td>
<td>3:15:17</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3:39:18</td>
<td></td>
</tr>
</tbody>
</table>

*M = 160 min

Fig. 7. Schematic showing the crack initiation and crack propagation segments in peened and un-peened specimens.
It is generally accepted that the total fatigue life $N$ is made up of initiation and propagation segments. It is reasonable therefore to assume that for an un-peened specimen

$$N = N_i + N_{pr} \quad (1)$$

where $N_i$ is the initiation fatigue life and $N_{pr}$ is the propagation fatigue life, while for a peened specimen

$$M = M_i + M_{pr} \quad (2)$$

where $M_i$ is the initiation fatigue life and $M_{pr}$ is the total propagation fatigue life.

Now, if $M$ is segregated into fatigue damage taking place in the compressed layer (denoted by the superscript cl) and fatigue damage taking place in the bulk material of the specimen (denoted by the superscript b), eqn. (2) becomes

$$M = M_i^{cl} + M_{pr}^{cl} + M_{pr}^{b} \quad (3)$$

The above equation implies that the initiation fatigue life for the peened component $M_i^{cl}$ takes place wholly in the compressed layer, while the propagation life $M_{pr}$ takes place in the compressed layer as well as in the bulk material. This assumption is only valid for cracks initiated from the top surface layers of the component. Cracks initiated within the bulk of the material (e.g. porosities or voids, hydrogen embrittlement) cannot be helped by the localised effects of shot-peening.

Once a crack has propagated beyond the compressed layer into the bulk material, its rate of propagation approaches that of an un-peened specimen. Now, since the depth of the compressed layer is relatively much smaller than that of the bulk material, it is then reasonable to assume that under the same cyclic loading conditions

$$N_{pr} \approx M_{pr}^{b} \quad (4)$$

and eqn. (3) becomes

$$M = M_i^{cl} + M_{pr}^{cl} + N_{pr} \quad (5)$$

Equation (5) implies that a large proportion of the fatigue life (at least $M-N$) is spent in the initiation and propagation of cracks in the compressed layer.

It is worth noting that the results of this study (Table 5) reveal that re-peening is most effective when the crack is still at the initiation and/or early propagation stages, i.e. where a large proportion of the fatigue damage is spent in combating the residual stresses in the compressed layer. Bombarding high-velocity shots onto the surface of a component would harden, would re-orientate the initiation slip planes and, in some instances, would obliterate surface microcracks already formed during dynamic loading. Further, because the fatigue activities are localised in the compressed layer for a considerable
made up of initial
assumption that for

\[ (1) \]

fatigue life

\[ (2) \]

propagation fatigue
taking place in the comp-

\[ (3) \]

for the peened
while the propa-
from the top sur-
not be helped by
ver into the bulk
peened specimen.
much smaller than
that under the

\[ (4) \]

life (at least \( M-N \))

\[ (5) \]

compressed layer.
reveal that re-
ion and/or early
damage is
layer. Bombarding
dharden, would re-
obliterate
ng. Further, because
for a considerable
portion of the total fatigue life, rejuvenation by re-peening could be carried
out most effectively at a relatively later stage of the specimen’s residual
fatigue life.

Surprisingly, the results of Table 5 indicate that the fatigue life obtained
after re-peening is more than the original fatigue life of a peened component
\( M \). There are three possible factors which could account for this, namely:
(i) strengthening of the compressed layers; (ii) improved coverage after re-
peening; and (iii) experimental scatter; all of which need to be explored in
future research. However, from the results obtained in both the peening and
re-peening experiments, it can be confidently concluded that complete re-
juvenation can be achieved even for specimens fatigued by up to 75% of their
estimated peened fatigue life \( M \), or their un-peened fatigue life, \( N \).

One interesting aspect of the present study is the effect of the re-peening
treatment upon the formation of sub-surface cracks. As pointed out in ref. 9,
sub-surface cracks have been found in peened components subjected to a
low-load high-cycle type of fatigue loading. Their locations and depths are
random, and are mainly determined by the metallurgical weaknesses in the
sub-surface structure and the corresponding state of stress in that layer. It is
difficult to see how re-peening using the same peening treatment can help in
rejuvenating the fatigue life of a component having sub-surface cracks, es-
pecially if these cracks initiate from locations slightly below the existing
compressed layer. One possible way to overcome this problem is to re-peen
the component using higher intensities.

**Effect of applied stress upon the compressed layer of peened components**

Figures 8 and 9 illustrate the effect of the magnitude of the applied stress
upon the resultant state of stress at the notch of a cylindrical specimen sub-
jected to pure bending. The initial magnitude of the compressive residual
stress pattern is assumed constant.

If the resultant surface stress in a peened component is compressive for
both the upper and lower faces of the specimen as depicted in Fig. 8 (b) (this
happens if the applied stress is low or moderate), the small surface cracks
will obviously be subjected to “compressive—compressive” cyclic stresses.
The behaviour of a crack under such conditions is difficult to predict (LEFM
does not apply). It is anticipated, however, that under these circumstances
the crack will be non-propagating, resulting in an improved fatigue life.

If, on the other hand, the applied stress is relatively high in magnitude the
resultant surface stress will be in a tensile—compressive mode as depicted in
Fig. 9(b). Large tensile stresses will be generated at the crack tip, thus prom-
oting the growth of the crack.

It is therefore reasonable to conclude that the resultant state of stress
plays an important role in the assessment of the effect of the peening and re-
peening treatments upon the resulting improvement in the fatigue life of the
component.
4. Conclusions

Both peening of partially fatigued un-peened specimens and re-peening of partially-fatigued previously-peened specimens, even at up to 75% of their estimated mean lives, yielded a considerable improvement in their respective fatigue lives. The results indicate that there exists a definite correlation between the initial crack depth prior to peening and the corresponding residual fatigue life achievable after peening. Specifically, a rapid decrease in the available fatigue life was promoted by the presence of increased depth of cracks prior to peening.

It was also demonstrated, using a simplified model, that the recovery of the fatigue life of a previously peened partially-fatigued component is most effective when the crack is still at the initiation and/or early propagation stages.

It is worth noting that the sample size for each experimental point was only four for the peening experiments and three for the re-peening experi-
and re-peening of up to 75% of their respective residual stresses. In view of the scatter inherent in all fatigue testing, a larger sample size per point is required. However, from the data available, this investigation consistently showed the effectiveness of the peening and re-peening treatments of partially fatigued specimens.

The objective of this study was to provide experimental results relating to the response of real materials to peening and re-peening of in-service components. It is believed that this is the first study of the effects of peening and re-peening upon partially fatigued components, and it is hoped that the information provided will guide the designer and the user of shot-peening towards the more effective use of both material and process.

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References