SURFACE AND AFFECTED LAYER OF SHOT PEENED TITANIUM

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Abstract
The basic properties on the peened surface and surface layer were studied experimentally on titanium (99.4%) and steel (0.45%C). The surface and the affected layer consist of dent, surface roughness, work hardened layer and residual stress. The centrifugal peening machine and steel shot was used. The ratio of work hardening and the other influence produced by shot peening for titanium are larger than steel.

1. INTRODUCTION
Titanium is a new material for automobile and aerospace industries. In these fields machine parts are required trustful properties for fatigue, stress corrosion, wear, etc. Shot peening produces the affected layer under peened surface, involving work hardening and work softening zone and the gradients of residual stress and half width. Shot peening is important process for the automobile and the aerospace industries, because the shot peened parts are improved the strength on fatigue, corrosion and wear, (1)(2)(3) but reports are comparatively few on the titanium as to change of mechanical properties after shot peening.

As the first step, shot peening was performed for titanium (99.4%) and steel (0.45%C) under various peening conditions such as coverage, shot size and velocity, thickness of specimen. Obtained data are diameter of dent, surface roughness, hardness distribution and surface residual stress.
2. PEENING CONDITIONS AND PROCEDURE
The experimental conditions of shot peening and specimen are shown in Table 1. The equipments for measurement of dent, surface roughness, hardness and surface residual stress are shown in Table 2.

Area coverage, defined from the ratio of the area of the dents to the whole peening area, initially increases rapidly and then slowly increases. Shot peening was performed until full coverage time.

Diameter of dent was measured crosswise and averaged. Three surface profiles of one specimen were recorded without cut-off and $R_{\text{max}}$ was calculated from the records.

Surface residual stress was calculated from the following formula using X-ray diffractometer.

$$\sigma_R = -\frac{E}{2(1+\nu)} \cot \theta_0 \frac{\partial 2\theta}{\partial \sin^2 \psi}$$

where $E = 113 \text{ GPa}$, $\nu = 0.321$ for titanium, and $E = 206 \text{ GPa}$, $\nu = 0.28$ for steel, $\theta_0$: standard Bragg angle, $2\theta$: diffracted angle, $\psi$: inlet angle of X-ray.

Microstructure of titanium is shown in Fig.1.

Table 1 Experimental conditions

<table>
<thead>
<tr>
<th>Peening machine</th>
<th>centrifugal type</th>
</tr>
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<tbody>
<tr>
<td>material</td>
<td>cast steel HV: 800</td>
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<table>
<thead>
<tr>
<th>Shot</th>
<th></th>
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<tbody>
<tr>
<td>size D mm</td>
<td>0.32, 0.55, 1.1, 2.2</td>
<td></td>
</tr>
<tr>
<td>velocity V m/s</td>
<td>17.5, 25, 30, 35</td>
<td></td>
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<table>
<thead>
<tr>
<th>Peening time T s</th>
<th>1 - full coverage time</th>
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</thead>
<tbody>
<tr>
<td>material</td>
<td>commercially pure titanium 99.4% (HV158)</td>
</tr>
<tr>
<td>Specimen</td>
<td>annealed carbon steel 0.45% C (HV180)</td>
</tr>
<tr>
<td>size W:25, L:25, t:10</td>
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<table>
<thead>
<tr>
<th>Residual stress</th>
<th>X-ray diffraction sin^2u method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti: (3 0 2) plain</td>
<td></td>
</tr>
<tr>
<td>steel: (2 1 1) plain</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Equipments of measurement

<table>
<thead>
<tr>
<th>Measurement</th>
<th>equipment</th>
</tr>
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<tr>
<td>Dent</td>
<td>tool microscope magnification: x30</td>
</tr>
<tr>
<td>Hardness</td>
<td>micro vickers tester load: 100, 200 g</td>
</tr>
<tr>
<td>Surface roughness</td>
<td>profile recorder magnification: x2000</td>
</tr>
<tr>
<td>Residual stress</td>
<td>X-ray diffractometer</td>
</tr>
</tbody>
</table>

Fig.1 Microstructure of titanium (99.4%)
3. EXPERIMENTAL RESULTS

The peened surface is consisted from a number of dent.

3.1 Diameter of dent (d mm)

Dent is a basic factor determining the surface roughness and the affected layer. (4)

The relation of diameter of dent to velocity and size of shot are shown in Fig. 2. From diameter of dent, velocity and size of shot, next equation is obtained.

\[ d = k_d \cdot D \cdot V^{1/2} \]  \hspace{1cm} (1)

Exponents of D and V are the same on steel and its coefficient \( k_d \) is similar to the steels. (5)

3.2 Surface roughness (Rmax \( \mu m \))

Surface roughness is a harmful factor in shot peening for fatigue strength of steel. (6)

The Influences of variables on surface roughness are shown in Fig. 3. By the same way as the
relations on dent, the following equation is obtained.

\[ R_{\text{max}} = k \cdot D \cdot V \]  \hspace{1cm} (2)

Exponents of D and V are also the same on steel. \(^{(7)}\)

3.3 Hardness distribution

Hardness distribution induced by shot peening is classified three types: work-hardening, work-non-hardening and work-softening. \(^{(8)}\)

As shown in Fig.4, the type of hardness distributions are work-hardening.

![Fig.4 Hardness distribution (Ti)](image)

Defining the maximum hardness \((H_{\text{max}})\) and depth of work hardened layer \((\delta)\) as shown in Fig.5(a), the influences of the kinetic energy of shot on them are shown in Fig.5(b) and (c). The more the kinetic energy of shot, the more the maximum hardness and the depth of work hardened layer. The work hardening ratio of titanium is larger than that of steel from 15\% to 25\%. The depth of work hardened layer of titanium is also larger than that of steel about 25\%.

![Fig.5 Maximum hardness and depth of work hardened layer versus kinetic energy of a shot](image)

3.4 Surface residual stress

As mentioned above, area coverage increases with peening time and surface residual stress also changes with peening time. The influence of peening time on surface residual stress is shown in Fig.6. In early stage, surface residual stress increases rapidly, and then saturates before full coverage. The saturate time of surface residual stress of titanium is shorter than that of steel.
In the case of shot peening, surface residual stress shows size effect for the thickness of steel specimen. Critical thickness $t_c$ shown in Fig. 8 means the minimum thickness to induce constant surface residual stress in the same shot peening conditions, and $t_c$ of titanium is larger than that of steel. The ratio of depth of work hardened layer to thickness of specimen is 5 as the same as steel.

When the thickness of specimen equals to the depth of work hardened layer, surface residual stress is not induced by shot peening.

The influences of peening variables on surface residual stress are shown in Fig. 7. The influence of diameter of shot is larger than that of velocity of shot.
size, velocity and diameter of dent:

\[ d = k_d \cdot D \cdot V^{1/2} \]

2) The relation between shot size and velocity and surface roughness is also similar to steel.

\[ R_{max} = k_a \cdot D \cdot V \]

3) Type of hardness distribution is work-hardening. The ratio of maximum hardness to the matrix is larger than that of steel from 15% to 25%. The depth of work hardened layer of titanium is from 0.2 to 1.2 mm, and larger than that of steel about 25%.

4) Surface residual stress of titanium is compressive from 250 to 420 MPa similar to steel.

5) The critical thickness of titanium is larger than steel about 25%. The ratio of thickness of specimen to the critical thickness is the same as steel.

5. REFERENCES
(1) J. C. Straub: Special Performance of Transmission Parts by Shot Peening, SAE730800,1, (1973)
(3) Shot Peening, 5th Ed., Wheelablator Corp., 24 (1965)