Wear Measurement of Engine Valve and Seat Insert Using a Confocal Laser Microscope

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Abstract: The minimization of valve and seat insert wear is a critical factor for consideration in the pursuit of engine performance improvement. In order to achieve this goal, an innovative simulator was developed with the ability to generate and control high temperatures up to 900°C and various speeds up to 80 Hz during motion, just as in the case of an actual vehicle engine. This wear simulator is considered to be a valid reproduction of the engine valve and seat insert wear process operating with various speeds during engine activity.

This work focuses on the different degrees of wear at three different singular test speeds (10 Hz, 25 Hz, & multi-Hz). In this study, the seat insert’s exterior surface temperature was controlled at 350°C, the cycle number was 2.1 × 10⁶ and the test load was 1960 N. The wear depth was measured before and after the testing using a confocal laser microscope. The wear depth of the valve and seat insert at 10 Hz was 29.9 (± 4.8) µm and 34.7 (± 1.4) µm, respectively. The mean (± Standard Deviation) wear depth of the valve and seat insert at 25 Hz was 74.7 (± 3.5) µm and 82.9 (± 2.7) µm, respectively. In the case of multi-Hz it was 48.5 (± 6.3) µm and 61.4 (± 5.4) µm, respectively. It was found that higher speeds caused a greater degree of wear than lower speeds under identical test conditions.

1. Introduction

The vehicle engines of today must function with a high level of power output, demonstrate superior fuel economy and perform with high durability. Such needs require strict control on the wear of the valve and seat insert, which are major components of any vehicle engine. The valve collides with and slides in the seat insert at high temperatures by means of the action of the valve spring. Occasionally, friction between the valve and seat insert is accompanied by a sliding phenomenon [1]. Certain phenomena of the valve and seat insert wear can be observed depending on the engine operation status. These include internal temperature, power output, speed or RPM (revolutions per minute) [2, 3]. Among them there has been no analysis of the wear rate and wear mechanism due to speed (RPM) change. A great amount of research throughout numerous studies has taken place concerning the valve and seat insert. However, the majority of such inquiries have only taken factors into consideration at a constant RPM while the actual condition for driving vehicles is fluctuation in the operational RPM. As such, it is difficult to examine the wear rate and the wear mechanism of the valve and seat insert depending on the engine RPM.

The objectives of this study focus on measuring the wear rate using a confocal laser microscope and observing the wear mechanism of the valve and seat insert depending on speed (RPM) changes.

2. Test Device and Method

2.1 Test Device

In order to examine the wear rate and the wear mechanism of the valve and seat insert [8, 9, 10], this study has applied a simulator that is exclusively used for valve and seat insert wear. This simulator takes
into account such aspects as speed change, temperature, load and friction between the valve and seat insert, etc., that represent the internal conditions of an actual vehicle engine.

The simulator exclusively used for this study has been designed to be similar to an internal combustion engine. It consists of three components: a hydraulic power unit, a control unit and a mechanical unit. The internal temperature of the chamber is monitored by five thermocouples. Three thermocouples are located 120° apart along the outer surface of the seat insert. The remaining two thermocouples are used to monitor the cooling system. In order to constantly maintain the desired internal temperature, cooling channels have been installed, which can control the temperature up to 900°C.

2.2 Test Method

The exhaust valves and seat inserts, currently used for an existing vehicle, were used as specimens. The valve material consists of STR35, a valve steel, and the seat insert material consists of HVS1-2, a sintered iron alloy. Table 1 shows the chemical composition of each material.

<table>
<thead>
<tr>
<th>Materials</th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
<th>Cu</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valve (STR35)</td>
<td>0.53</td>
<td>0.31</td>
<td>9.00</td>
<td>21.00</td>
<td>-</td>
<td>3.87</td>
<td>-</td>
<td>Bal</td>
</tr>
<tr>
<td>ValveSeat (HVS1-2)</td>
<td>1.1</td>
<td>-</td>
<td>7.5</td>
<td>2.0</td>
<td>2.0</td>
<td>15</td>
<td>-</td>
<td>Bal</td>
</tr>
</tbody>
</table>

The hardness of each specimen was measured after having been ground using a Vickers hardness tester. The hardness obtained in this manner was 419 (Hv 500g) for the valve and 397.7 (Hv 500g) for the seat insert.

Wear tests were performed for three speeds, 10Hz, 25Hz and multi-Hz (10Hz-25Hz). To achieve objectivity and consistency, the tests were performed for six specimens per speed under identical test conditions. The applied test temperature was 350°C at the outer surface of the seat insert (760°C at valve face). The valve was opened and closed $2.1 \times 10^6$ times, and the test load was 1960N.

Wear depth was measured before and after the test using a confocal laser microscope (Model OLS 1100 made by Olympus, Resolution 0.01μm). Then, the measured values before and after the test were analyzed and compared. In addition, using a SEM (Model JSM 6400JEOL made by JEOL, Resolution 4nm), the valve face and seat insert surfaces were observed before and after the test to examine the wear mechanism.

3. Test Results

3.1 Wear Depth

To guarantee the reliability of the measurements and minimize differences of the wear depth caused by eccentricity, the measured area was divided 90° apart along the surface of the valve and seat insert (see Fig. 1).

Each measured area was scanned 10 times (see Fig. 2), and the scanned data were averaged for the wear depth of the each measured area.
Fig. 3 shows one example of the three-dimensional wear scar profile at the maximum contact area of a seat insert at 25Hz, which was measured using the OLS1100.

Fig. 4 illustrate the wear depth of the valve and the seat insert for each speed (Hz) with statistical data. The mean (± Standard Deviation) wear depth of the valve and seat insert at 10Hz was 29.9 (± 4.8)㎛ and 34.7 (± 1.4)㎛, respectively. The mean (± Standard Deviation) wear depth of the valve and seat insert at 25Hz was 74.7 (± 3.5)㎛ and 82.9 (± 2.7)㎛, respectively. In the case of multi-Hz it was 48.5 (± 6.3)㎛ and 61.4 (± 5.4)㎛, respectively.

As can be seen from the measured values in Table 3, wear depth increases as the speed (Hz) increases. Here, since an increase in the Hz signifies an increase in the RPM of the vehicle engine, a severe increase in RPM may be responsible for such drastic increase in the valve and seat insert wear.

3.2 Wear Mechanism
(1) Adhesive Wear
During sliding, fragments from one surface contact fragments from the other surface. When such contact does not take place, fragmentation may not occur at the interface. As a result, movable fragments will be generated. The roughness of each surface has substantial impact on the adhesive wear.

(2) Shear Strain
The result of shear strain exceeding the limit of the plastic deformation of the material surface can be classified as wear. It can be observed that in the case of the valve and seat insert, the typical
appearance of the shear strain generated due to wear is identical to the flow in the ridge or radial direction.

(3) Abrasive Wear
Abrasive wear occurs due to the cutting action of asperities or hard particles on a hard surface. The surface is damaged by the interaction of the separated particles that are confined between the sliding surfaces of the valve and seat insert.

(4) Surface Fatigue Wear or Pitting
The loading and unloading cycles that expose the material cause a crack to form on or below the material surface, creating a large fragment or damaging the surface leaving large holes in its end. The form of wear similar to this type of surface fatigue wear can be seen from a brittle material that breaks into large fragments. Upon repeated sliding or rotation of surfaces, surface fatigue wear is frequently noticed from the seat insert as it sinters from the iron powder.

4. Discussion and Conclusion
1) The mean wear depth (± Standard Deviation) of the valve and seat insert at 10Hz was 29.9 (±4.8) μm and 34.7 (±1.4) μm, respectively. In addition, the mean wear depth (Standard Deviation) of the valve and seat insert at 25Hz was 74.7 (±3.5) μm and 82.9 (±2.7) μm, respectively. Lastly, the mean wear depth (± Standard Deviation) of the valve and seat insert at multi-speeds (variable from 10Hz to 25Hz) was 48.5 (±6.3) μm and 61.4 (±5.4) μm, respectively. Therefore, it can be seen that the wear depth of the valve and seat insert increases sharply in accordance with a rise in the speed (Hz). According to these results, an increase in the engine revolution may cause the engine performance of a vehicle to decrease due to the rapid wear of the valve and seat insert.

2) From the valve wear mechanism, the following phenomena were observed:
- At 10Hz, the following types of wear were observed: adhesive wear causing sliding of the valve and seat insert due to friction between the valve and seat insert; and shear strain wear in a radial direction resulting in the breakdown of metal particles due to the plastic deformation in the material, or fragments being created.
- At 25Hz and multi-Hz, abrasive wear that occurs due to metal particles created by shear strain was observed.
3) From the seat insert wear mechanism, the following phenomena were observed:
- At 10Hz, adhesive wear occurring at the beginning stage of metal wear was primarily observed.
- At 25Hz and multi-Hz, surface fatigue wear was noticed because the seat insert was made from a sintered iron powder.
In addition, at 25Hz and multi-Hz, abrasive wear by metal particles was often seen.

References