Bending Fatigue Strength of Case-Carburized Spur Gears with Boss

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Abstract—Studies on the spur gear, to increase the bending fatigue strength have been published by adopting gear with high pressure angle and positive addendum modification factor. However, studies on the spur gear with wide boss have been hardly published. In this project, the bending fatigue test and the hardness measurement of hardened layer were carried out for various case-carburized spur gears with boss, and S-N curves and case depth were obtained. Effects of case depth and boss width on the bending fatigue strength of case-carburized gears were examined. From this project, a method to select the suitable boss width for the bending fatigue strength of case-carburized gears with boss was determined.

Keywords—gear; case-carburized; bending fatigue strength; crack; boss width; casedepth

I. INTRODUCTION

In order to increase the bending fatigue strength at the tooth root fillet of gears, gears with high pressure angle and positive addendum modification factor are generally adopted[1]. Many studies on the bending fatigue strength of these gears have been published [1-6]. However, studies on bending fatigue strength of gears, increased the tooth thickness at the tooth root fillet in the face width direction by using wide boss, have been hardly published.

In the present paper, effects of boss width and case depth on the bending fatigue strength of case-carburized spur gears were investigated. The bending fatigue test, the hardness measurement and the observation of micro- and macro-structure of hardened layer were carried out for case-carburized spur gears with different case depths and boss widths, and S-N curves and case depths were obtained. Effect of case depth and boss width on the bending fatigue strength of case-carburized spur gears were examined. A method to select the suitable boss width for the bending fatigue strength of case-carburized gears with boss was determined.

II. EXPERIMENTAL PROCEDURE AND APPARATUS

A. Test Gears

In order to examine effects of the case depth and the boss width on bending fatigue strength of the case-carburized spur gears, bending fatigue test and hardness measurement were carried out. Main dimensions and gear sign of test gears used in this experiment are shown in Table 1. Figure 1 shows the shape and the geometry of the test gears. Test gears were hobbed, and then case-carburized. Three kinds of case depth \(d_e = 0.40, 0.75, 1.16\) mm \((d_e : \text{effective case depth for } HV \geq 550)\) and three kinds of boss width \(b_b (= 10, 12, 14 \text{ mm})\) were used.

<table>
<thead>
<tr>
<th>Gear sign</th>
<th>GA0</th>
<th>GB0</th>
<th>GC0</th>
<th>GA1</th>
<th>GB1</th>
<th>GC1</th>
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<td>Pressure angle (\alpha_0)</td>
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<td>Face width (b) mm</td>
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<td>Boss width (b_b) mm</td>
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<tr>
<td>Effective Case depth (d_e) mm</td>
<td>0.40</td>
<td>0.75</td>
<td>1.16</td>
<td>0.40</td>
<td>0.75</td>
<td>1.16</td>
<td>0.40</td>
<td>0.75</td>
<td>1.16</td>
</tr>
<tr>
<td>Material and heat treatment condition</td>
<td>SNC815, Case-carburized</td>
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</table>

B. Macro-Structure of Gear Tooth

Middle sections of the face width of test gear were buffed and then nital liquid for corrosion were used to observe the case depth and photographs were taken.

C. Micro-Structure Observation

Structure observation using the metallurgical microscope at position near tooth surface and position distant from tooth surface of the Hofer’s critical section of $\theta = 30^\circ$ [0: tangential angle (angle between center line of tooth profile and tangent to root fillet curve)] at the tooth root fillet of the middle sections of the test gears were carried out.

D. Hardness Measurement

Hardness distribution in the normal direction of the tooth surface at the Hofer’s critical section of the test gear were measured and effective case depth $d_e$ were determined.

E. Bending Fatigue Test

The bending fatigue test machine [6] used in this experiment consists of a fuel injection pump for diesel engine and its driving apparatus $\textcircled{1}$, pressure controller $\textcircled{2}$, loading apparatus $\textcircled{3}$ as shown in Fig. 2. The frequency of load applications is about 670 c/min.

III. RESULT AND DISCUSSION

A. Hardened Layer

Figure 3 shows photographs of macro-structures of the test gears with uniformed hardened layer along the tooth surface and the gear-side, for any kind of gears can be recognized.

B. Micro-Structure of Gear Materials

Figure 4 shows photographs of micro-structure of hardened layer (surface) near the position of Hofer’s critical section and unhardened (core) position distant from the tooth surface of test gears GB0. In Fig. 4, the micro-structure of hardened layer (surface) is perfect martensite structure and mixed structures of ferrite and pearlite in the micro-structure of unhardened (core).

C. Hardness Distribution

Figure 5 shows the measured results of hardness distributions in the normal direction of the tooth surface at the position of Hofer’s critical section of the test gears GA0, GB0 and GC0. Effective case depths of test gears GA0, GB0 and GC0 are 0.40, 0.75 and 1.16 mm respectively.

Figure 3. Photographs of macro-structure of test gears

(a) GA0 (b) GB0 (c) GC0 (d) GA1 (e) GB1 (f) GC1

Figure 4. Microphotographs at Hofer’s critical section (GB0)
D. Bending Fatigue Strength

Figure 6 shows bending fatigue test results for test gears GA0, GB0 and GC0. In Figure 6, the abscissa denotes the number of load cycles \( N \), and the ordinate the normal tooth load \( P_n \) and the root stress \( \sigma_t \) calculated by the practical formula proposed by AidaTerauchi [7]. It is seen from Fig. 6 that the maximum bending fatigue limit load \( P_{nu} \) of the test gears is obtained in GB0 and there is an optimum case depth for \( P_{nu} \) as in the case of gears without boss.

Figure 7 shows bending fatigue test results for test gears GB0, GB1, and GB2. It is seen from Fig. 7 that the maximum \( P_{nu} \) of the test gears is when \( b_b/b = 1.4 \).

Figure 8 shows bending fatigue limit loads \( P_{nu} \) obtained from the bending fatigue test results of the test gears shown in Table 1. It is seen from Fig. 8 that the largest value of \( P_{nu} \) in any case of boss width is GB, and \( P_{nu} \) of test gears increases with an increasing boss width \( b_b \).

Figure 9 shows a three-dimensional graph of a relation between \( b_b/b, P_{nu}/P_{nuB0} (P_{nuB0} of GB0) \) and \( d_e \). It is seen from Figure 9 that \( P_{nu}/P_{nuB0} \) increase with increasing \( b_b \). But, in some cases (gray area in Figure 9) of too thick case depth \( P_{nu}/P_{nuB0} \) become smaller than 1 irrespective of value of \( b_b \). This should be considered in bending strength design of case-carburized gears with boss.
E. Bending Fatigue Crack

Figure 10 shows photographs of cracks of test gears GB0, GB1 and GB2. Figure 11 shows bending fatigue crack propagations at the end of face width of test gears GB0, GB1 and GB2. It is seen from Fig. 11 that the position of bending fatigue crack initiation of the test gears with boss moves from the position of the Hofer’s critical section at the tooth root fillet towards the tooth tip with an increasing boss width \( b_b \). This might be because tooth thickness at the Hofer’s critical section increases with an increasing \( b_b \).

IV. CONCLUSIONS

The bending fatigue strength of case-carburized spur gears with boss was determined by performing the bending fatigue test. Main results obtained from this investigation are summarized as follows.

1. The bending fatigue limit load \( P_{nu} \) of case-carburized spur gears with boss increases with an increasing boss width \( b_b \). There is also an optimum case depth for \( P_{nu} \) in case-carburized spur gears with boss as in the case of case-carburized spur gears without boss.

2. The position of bending fatigue crack initiation of the case-carburized spur gears with boss moves from the position of the Hofer’s critical section at the tooth root fillet towards the tooth tip with an increasing boss width \( b_b \).

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