Review

Ultrasonic Fatigue Property of Metal Injection Molded Cold Work Tool Steel

Kenji Doi*1, Kazuki Hanami*1, Tsuneo Teraoka*1, Syuntaro Terauchi*1 and Takashi Sugimoto*2

*1Osaka Yakin Kogyo Co., Ltd., Higashiyodogawa-ku, Osaka 553-0005, Japan.
*2Kansai University ORDIST, Suita, Osaka 564-8680, Japan.

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SYNOPSIS
High cycle fatigue properties of Metal Injection Molded (MIM) cold work tool steel and wrought steel (JIS SKD11) were investigated via ultrasonic fatigue test. The wrought steel specimens were tempered at 423 K for 1 hour. On the other hand, the MIM steel specimens were tempered at various temperatures in order to evaluate effect of tempering temperature on fatigue property. The ultrasonic fatigue tests were performed in the fatigue life range of N=10^3−10^8. Fatigue strength of the MIM steel specimens was equivalent to that of the wrought steel specimens. Fatigue strength of the MIM specimens declined with increasing tempering temperature. The results of microstructure observation showed that the diameter and shape of carbide of the MIM specimens were more uniform than those of the wrought steel specimens.

KEYWORDS
metal injection molding, ultrasonic, fatigue, cold work tool steel, SKD11

1 Introduction
Mechanical properties of metal injection molded material have been standardized recently. Many investigations of static mechanical properties have been reported, but few investigations of kinetic mechanical properties have been reported. It is important to indicate kinetic mechanical properties when MIM parts are applied to parts for machine structural use that are subjected to cyclic stress. In this paper, ultrasonic fatigue tests were applied to the MIM steel specimens and the wrought steel specimens by using of cold work tool steel (JIS SKD11), and high cycle fatigue properties of the specimens were investigated.

2 Experimental Methods
The cold work tool steel powder with an average particle size of 10.22 µm was used for MIM specimens. The chemical compositions of the metal powder and the material for the wrought steel specimens are presented in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Cr</th>
<th>Mo</th>
<th>V</th>
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<tr>
<td>Wrought steel</td>
<td>1.45</td>
<td>0.26</td>
<td>0.40</td>
<td>0.023</td>
<td>0.001</td>
<td>11.83</td>
<td>0.84</td>
<td>0.24</td>
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<tr>
<td>Powder for MIM</td>
<td>1.55</td>
<td>0.31</td>
<td>0.38</td>
<td>0.012</td>
<td>0.013</td>
<td>11.58</td>
<td>1.10</td>
<td>0.38</td>
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</table>

The powder was mixed with polymer binder and wax by using a pressurized kneader to form the feedstock. The feedstock was injection molded into bar. After solvent extraction, thermal debinding was performed, and followed by sintering. After the bars were shaped into specimens for fatigue tests by machining, the specimens were quenched at 1,040 °C for 1 hr, and tempered on two kinds of conditions to investigate effect of heat treatment on fatigue property. The conditions for tempering were as follows; low-temperature tempering; 150 °C×4 hr, high-temperature tempering; 515 °C×3 hr−510 °C×3 hr. On the other hand, after the wrought steel bars were shaped into fatigue test specimens by machining, the specimens were quenched at 1,040 °C for 1 hr and then were tempered at 150 °C for 4 hr. Fig. 1 shows dimensions of the specimens. Characterization of the specimens was accomplished by...
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Rockwell hardness and density measurements. In addition, the carbon content and the oxygen content of the MIM specimens were measured to evaluate their soundness. Ultrasonic fatigue tests and microstructure observation were carried out. The ultrasonic fatigue testing system used in this study was USF-2000 provided by SHIMADZU CORPORATION. The ultrasonic fatigue tests were performed in the fatigue life range of N = 10^3 – 10^8 at a frequency of 20 kHz ± 0.5 kHz.

3 Results and Discussion

3.1 Specimens

The carbon content and the oxygen content of the MIM steel specimens are 1.80 wt% and 0.008 wt% respectively. The carbon content increased after sintering. This indicates residual carbon in the specimens. Table 2 shows the results of density and Rockwell hardness measurements.

3.2 Ultrasonic fatigue test

Fig. 2 shows the results of the ultrasonic fatigue tests. As a result, for the wrought steel specimens, fatigue life increases gradually as stress falls down to 750 MPa, below which it increases rapidly. The S-N curve indicates that fatigue strength of wrought steel specimens is 675 MPa.

As the result, for the MIM steel specimens tempered at low-temperature, fatigue life increases gradually as stress falls down to 800 MPa. The S-N curve reaches a plateau at 725 MPa. On the other hand, for the MIM specimens tempered at high-temperature, fatigue life increases gradually as stress falls down to 700 MPa. The S-N curve reaches a plateau at 625 MPa.

3.3 Fracture surface observation

Fig. 3 shows the fracture surfaces of the wrought steel specimens and the MIM steel specimens. All the fracture surfaces in this study show that the fracture took place around circumference of the specimens. In addition, single starting point of fracture is found in each specimen. In general, resonant frequency of ultrasonic fatigue test changes as fracture advances. However no change in resonant frequency was found during fatigue test for all the specimens. This result indicates that the fracture advances in an instant, and then the specimens become breaking.

3.4 Microstructure observation

Fig. 4 shows microstructure of the wrought steel specimens. Diameter and shape of carbides in wrought

<table>
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<tr>
<th>Material</th>
<th>Density (g/cm³)</th>
<th>HRC</th>
</tr>
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<tbody>
<tr>
<td>Wrought steel</td>
<td>7.69</td>
<td>63.4</td>
</tr>
<tr>
<td>MIM tempered at low-temperature</td>
<td>7.66</td>
<td>64.1</td>
</tr>
<tr>
<td>MIM tempered at high-temperature</td>
<td>7.66</td>
<td>60.5</td>
</tr>
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</table>

Fig.2 S-N diagrams for cold work tool steel (JIS SKD11).

Fig.3 Fracture surfaces by ultrasonic fatigue test at 800MPa for cold work tool steel (SKD11). A part surrounded pecked line indicates a starting point of the fracture.
steel are variable. In addition, carbides expanded along the rolling direction. Microstructure of the MIM specimens is shown in Fig. 5. The microstructure of crossing section and that of axis section are the same for each specimen. Carbides are round and fine, and are uniformly distributed. Maximum particle size of carbide of the wrought steel specimens and the MIM steel specimens are 52.5 μm and 6.4 μm respectively. It is known that particle size and shape in cold work tool steel affect fatigue life. Thus, it can be stated that the superiority of fatigue strength of the MIM specimens tempered at low-temperature to that of the wrought steel specimens is attributable to the differences in carbide.

3.5 Relation between fatigue strength and hardness
Fig. 6 shows the relation between fatigue strength and Rockwell hardness for cold work tool steel (JIS SKD11). Fatigue strength increases with increasing hardness. It is known that material tempered at a low-temperature is superior to material tempered at a high-temperature in fatigue strength even if the same material. The results of this study correspond to general tendency for metal.

4 Conclusions
High cycle fatigue properties of metal injection molded cold work tool steel and wrought tool steel (SKD11) were investigated via ultrasonic fatigue tests. The results are summarized as follows.
(1) Ultrasonic fatigue test is available to investigate high cycle property of metal.
(2) The obtained S-N curves are worthy of evaluating MIM specimens.
(3) The fatigue strength of the wrought steel specimens is 670 MPa. The fatigue strength of MIM specimens tempered at a low-temperature and tempered at a high-temperature are 725 MPa and 625 MPa respectively.
(4) The relation between fatigue strength and Rockwell hardness shows that fatigue strength increases with increasing hardness.
(5) Diameter and shape of carbide of the wrought steel specimens are variable. In addition, carbides of the wrought steel specimens expand along the rolling direction. On the other hand, carbides of the MIM steel specimens are round and fine, and are uniformly distributed. It can be stated that these are the factors...
that the MIM specimens are superior to the wrought steel specimens in fatigue strength.

References