THERMAL FATIGUE PROPERTIES OF LASER PEENED HOT WORK DIE STEEL (H13)

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ABSTRACT

Application of laser peening for hot work die steel (JIS-SKD61, AISI-H13) was investigated by thermal fatigue test. Prior to the test, residual stress on the specimen of laser peened surface was approximately -1000 MPa, and the depth of the created compressive stress was approximately 1800µm. During the test, compressive residual stress of laser peened area was higher than that of the area not laser peened. After the test, compressive residual stress for the laser peened area had almost disappeared. The increase of crack growth resistance by laser peening was shown by crack measurement.

INTRODUCTION

Several surface modifications are applied to increase the life of die casting die. Thermal fatigue and soldering are the causes of damage for die casting die. Applying compressive stress and hardening the surface is an effective method to prevent thermal fatigue. For reasons of high temperature environment and cost of treatment, nitriding is often used. Among the methods for surface modifications, shot peening is used to increase fatigue property of mechanical parts. However, since the depth of residual stress is only 10µm for quenched steel such as hot work die, shot peening with nitriding is an effective process for hot work die.

To prevent fatigue in depth not reachable by mechanical shot peening, Laser Peening treatment (LP treatment) is available to apply the necessary residual stress. Increase of fatigue strength was detected at room temperature[1]. In this case, an increase of thermal fatigue property of hot work die will be expected.

This paper describes the effect of LP treatment for thermal fatigue property of hot work die steel (AISI-H13, JIS-SKD61) by means of thermal fatigue test. The residual stress applied by LP treatment was measured by X-ray stress measurement. After the thermal fatigue test, the suitability of LP treatment for hot work die will be discussed by means of crack measurement.

EXPERIMENTAL PROCEDURE
**SPECIMEN PREPARATION**

LP treatment was performed after the heat treatment. Table 1 shows the conditions of LP treatment. Figure 1 shows the shapes of specimen and irradiation area of LP treatment. Figure 2 shows the overview of LP treatment. Before processing, an opaque overlay (black paint) was applied to absorb the laser beam, after which a transparent overlay (water curtain) was applied to the surface to be treated. The laser beam passes through the water curtain to strike the opaque overlay which vaporized and generated a high-pressure shock wave which propagates into the material and yielded the material micro-structurally. Because of intermittent irradiation, the LP treatment area overlapped with each other.

**THERMAL FATIGUE TEST**

The specimen was heated up to 843K for 160 seconds by exposing it with a heat block, and then it cooled to 373K for 15 seconds by dipping the specimen in a water bath [2]. This test cycle reached up to 1.5x10^4 cycles. During the thermal fatigue test, residual stress was measured at each designated cycle point. After the test, the surface of the specimen was observed at the LP and NLP (Non-LP) areas. The specimen was cut and the cracks in the sectional area were observed and measured. The ranges of the crack measurement were 10 mm in width. Total number of cracks and maximum crack length were measured in these ranges.

**X-RAY STRESS MEASUREMENT**

Table 2 shows the conditions of X-ray stress measurements. The apparatus used for X-ray stress measurement was a RIGAKU MSF-2M with a parallel beam system and omega-goniometer. For X-ray stress measurement, αFe211 diffraction was used. For the measurement of residual stress distribution of the specimen surface, RIGAKU RINT-2400 with rotate target, collimator (0.1mm diameter) and PSPC detector were used. The areas of residual stress measurement were 5mm square. Two areas were measured at LP and NLP area,
and these positions are shown in Figure 1. Electrical polishing was used to measure the residual distribution for the sectional area.

RESULT AND DISCUSSION

RESIDUAL STRESS BY LP TREATMENT

Figure 3 shows the residual stress distribution from the surface to the inside of the specimen. At the LP area, the residual stress on the surface was over -1000MPa. which gradually decreased as the distance from the surface increased and achieved 0MPa at 1800µm. At the NLP area, because of machining, residual stress on the surface was about -500MPa. Residual stress was not detected beyond 50 µm which was reached by electrical polishing.

Figure 4 shows the residual stress distribution on the specimen surface. In Figure 4, X-direction indicates the diameter direction and Y-direction indicates the radial direction of irradiation spot. The dimension of irradiation spots is also shown in Figure 4. Compressive residual stress ranging from about -400 to -800 MPa existed in the LP area. Though, these stresses changed periodically as the distance increased, the stresses did not correspond closely to each irradiated position. The behavior of residual stress distribution at overlapped spots can be clarified by observing two partially overlapped irradiated spots. This particular subject will be discussed in our future report.

In the NLP area, weak tensional stress of the Y-direction existed at about 3mm from the boundary of LP and NLP area. This phenomenon was due to the reaction of compressive stress applied in the LP area. Though decrease of compressive residual stress was shown in the X-direction, it did not become tensional.

Table 2. Conditions of X-ray stress measurement

<table>
<thead>
<tr>
<th>Apparatus</th>
<th>MSF-2M / RINT-2400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffraction</td>
<td>αFe 211</td>
</tr>
<tr>
<td>Target</td>
<td>Cr</td>
</tr>
<tr>
<td>Tube Voltage</td>
<td>30 kV / 50kV</td>
</tr>
<tr>
<td>Filament Current</td>
<td>8mA / 200mA</td>
</tr>
<tr>
<td>Measurement Method</td>
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</tr>
<tr>
<td>Stress Constant</td>
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</tr>
</tbody>
</table>

Figure 3. Distribution of residual stress for sectional area before test

Figure 4. Distribution of residual stress on the surface
**THERMAL FATIGUE TEST**

Figure 5 shows the changes of residual stress during the thermal fatigue test. At the LP area, about -1100 MPa of high compressive stress existed before the test. During the thermal fatigue test, compressive stress decreased drastically to -600 MPa at $10^1$ cycles. After the cycles, residual stress decreased slightly as test cycles increased. Finally, residual stress converged about -400 MPa.

On the other hand, at the NLP area, approximately -500 MPa of residual stress existed before the test. Residual test decreased slightly as the test cycles increased. After the $10^1$ cycles, though the same tendency showed at each area, residual stresses at the LP area were approximately 200 MPa higher than at the NLP area at every one of the test cycles.

**EFFECT OF LP TREATMENT**

Figure 6 shows the overview of the specimen surface after the thermal fatigue test. In Figure 6, the inside of the white box is the LP irradiated area. Due to the forming of an oxide layer, the observation was done after the oxide layer was removed by buffing. Though checkered cracks formed in the NLP area, distinct crack was not observed in the LP area. For further detailed observation of these cracks, microscopic observation was made after removing the oxide with emery paper #600. Figure 7(a) and (b) show the result of this observation.

In the LP area (Figure 7 (a)), 10 µm width of checkered fine cracks at intervals of about 50 µm were observed. In the NLP area (Figure 7 (b)), only the 200 µm width of wide cracks were observed. Fine cracks such as in the LP area were not observed in the NLP area. Figure 8 (a) and (b) show microphotographs of sectional area for each specimen. At the LP area (a), Several cracks with length of 100 µm containing oxide were observed, and a large number of fine cracks with length of 10-20 µm were also observed. At the NLP area (b), cracks too wide for microscope observation were observed. These observations correspond to the surface observation as described in Figure 7, (a) and (b).

Figure 9 shows the result of crack measurement in the specimen section. Comparing the maximum length of LP area with that of NLP area, the former was about 170 µm, and the
The latter was about 1800 µm. The maximum crack length decreased to approximately 10% with the LP treatment.

Figure 10 shows the distribution of crack length. Many fine cracks less than 50 µm existed in the LP area. On the other hand, more than 100 µm of large cracks existed in the NLP area. This result reflects the sectional observation illustrated in Figure 8. Figure 11 shows the curves of residual stress distributions for each area. In this figure, the result for the specimen before the test is shown. The residual stress in the LP area on the surface was about -200MPa. It decreased slightly as the distance from the surface increased, similar to the tendency in the NLP area. Though in the LP area, the residual stress became constant at about 400 µm from the surface, in the NLP area, the residual stress was approximately -200MPa between the surface to approximately 1300 µm. The depth of existence of residual stress in each area corresponded to the depth of crack length in each area. Thus, the residual stresses after the test were formed by the oxide inside the crack which is
due to the wedge effect. In the LP area, the residual stress that was applied before the test had almost disappeared by heating during the test. However, microphotograph observation and crack measurement confirmed the increase of crack resistance by LP treatment. It can be considered that this phenomenon is the result of decreased crack growth speed by high compressive residual stress in the LP area during the thermal fatigue test as described in Figure 5 (Thermal Fatigue Test)

CONCLUSION

Applicability of LP treatment for hot work die was investigated by thermal fatigue test. The results obtained are as follows:

1. Over -1000MPa of high compressive residual stress was observed on the surface of the LP area by measuring residual stress distributions from the surface to the inside. The depth of residual stress was approximately 1800µm.
2. During the thermal fatigue test, residual stresses in the LP area were approximately 200MPa higher than the NLP area at all of the test cycles.
3. Increase of crack resistance by LP treatment was confirmed by microphotograph observation and crack measurement. Furthermore, the maximum crack length decreased to 170µm which compares to the crack length of 1800µm in the NLP area.
4. In measuring the residual stress distribution after the thermal fatigue test, the residual stress which was applied before the thermal fatigue test had almost disappeared by heating during the test.

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REFERENCES