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Deflection simulation of a die installed in an HPDC machine to predict the die life

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This research proposed a method to predict heat-checking. The analysis of the die surface for a flat part revealed that heat-checking occurs at the portion causing plastic deformation. High stress concentration during curing causes the Mises stress to be above the yield stress. The diagram illustrating the maximum value of the stress difference (= Mises stress- yield stress) well predicted the crack positions observed in the die after 120,000 shots. The surface strain analysis revealed that the initiated crack widens with repeated expansion and contraction. The mode II mechanism of fracture mechanics well explains the crack initiation and propagation.

Keywords: *High-pressure die-casting, Heat-checking, Thermal distortion, Stress simulation.*

1. Introduction

Heat-checking (cracking) and gross-cracking typically shorten the durability of an HPDC die. In the previous study [1-3], we found that heat-checking occurs where the Mises stress exceeds the yield stress during curing. The surface strain analysis revealed that the initiated crack widens with repeated expansion and contraction. The coincidence of the stress analysis with the actual observation demonstrated that the mode II mechanism of fracture mechanics well explains the crack initiation and propagation.

In the present study, the author uses a similar approach to reproduce the three elements: the die-locking force, the casting pressure, and the thermal stress. The casting and solidification simulation revealed the temperature distribution of the die. The FEM stress analysis evaluated the stress causing heat-checking. The detailed mechanism is demonstrated and the method to enable precise prediction of the heat-checking is proposed.

2. Simulation

First, an FDM flow and solidification simulation calculated the temperature distribution of the die insert. Second, the thermal deflection of the die insert in the die holder was calculated from the temperature distribution. Finally, the deflection of the die insert caused by the additional die-locking force as well as casting pressures was simulated. The die and machine were modeled in accordance with the actual installation. The HPDC operation used an oil-based die-release agent. The injection conditions and additional parameters for the simulation were selected so as to follow the actual HPDC operation. Typically, the initial temperature of the molten metal JIS-ADC12 was 580°C. The slow injection speed was 0.3 m/s, and the high injection speed was 1.7 m/s. The curing time was 5.5 s. One shot of the actual casting process comprises five stages. A total of 20 shots reached the steady state temperature distribution of the die. The die-locking force was applied from the toggle of the movable platen with a load of 2,450 kN. A casting pressure of 60 MPa was vertically and homogeneously applied on the cavity surface in order to simulate the squeezing pressure. The detail of these installations was illustrated in the previous paper [1-3].

3. Results and discussion

Fig. 1 shows a detailed variation of cavity surface temperature at points 1 through 12 during the 20th shot. The point number corresponds to the numbers in Fig. 2. The horizontal axis shows the time from the first shot as well as the time from the onset of this shot. The curing after the injection starts from 560.5 s. The timings discussed are indicated by the vertical lines in the diagram.

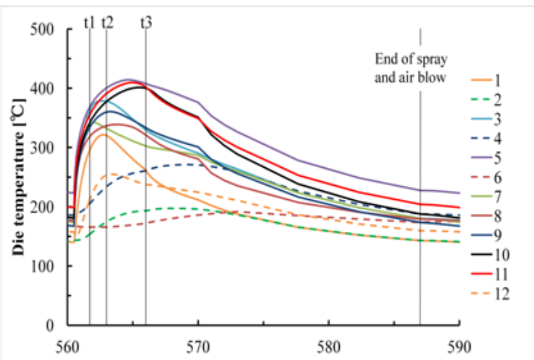

Fig. 1 Variation of temperature at points 1 through 12 during the 20th shot. The injection ends at 560.5 s (0.5 s).

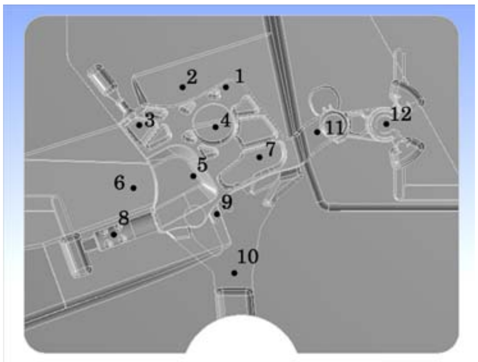

Fig. 2 Points 1 through 12 used in stress calculation for the movable-die surface.

The surface temperature increases rapidly after injection and shows a peak, but the timing showing the peak is slightly different from peak to peak. In the diagram, the curing finally ends at t3. The timings t1 = 561.7 s and t2 = 563.0 exist during curing, followed by the timings at the end of die opening and at the end of part release from the die. The end of spray-air blow after parting the die is also indicated at 587.0 s. The highest thermal stress at the area of focus on the die surface takes place during curing. In the previous study [1, 2], we used timing, typically t2, for the judgment (Mises stress> yield stress) at the analyzed position. However, the temperature-peak time differs from point to point, as shown in Fig. 1. The difference (= Mises stress- yield stress) will be proportional to the degree of plastic strain. In order to avoid this issue and to best evaluate the place of heat-checking, the stress difference at t1, t2 or t3 was separately calculated at each point and the maximum value of the stress difference was plotted as shown in Fig. 3.

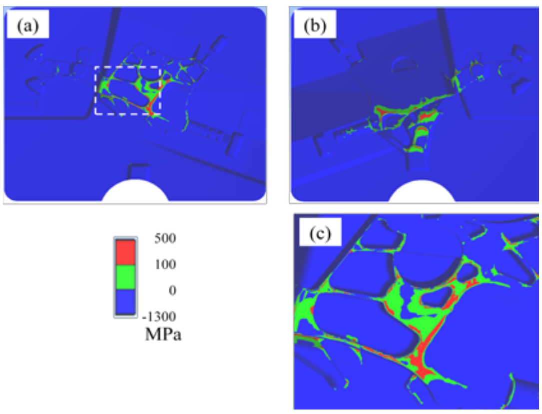

Fig. 3 Stress difference (= Mises stress- yield stress) diagram, illustrating the maximum value observed at three timings (t1, t2, and t3). (a) Stationary-die side, (b) movable-die side and (c) magnified view of (a).

This diagram was found to be valuable in determining whether heat-checking has occurred. Fig. 4 shows an actual heat-checking which corresponds to the enlarged view of the square area enclosed by the dotted line in Fig.3 (c). The coincidence confirmed the validity of the mode II mechanism. Fig. 3(b) shows the similar stresses on the stationary-die side. The high stress difference appears just beyond the gate. Thus, typical heat-checking just beyond the gate is predictable.

Fig. 4 Transcribed heat-checking observed in the part on the movable-die side after 120,000 shots. Enlarged view of the square area enclosed by the dotted line in Fig.3 (a).

4. Conclusion

FEM stress analysis of the die revealed that heat-checking occurs at the localized portion where plastic deformation takes place during curing. The diagram showing the maximum value of the stress difference during curing well predicted the crack positions observed on a flat part of the die after 120,000 shots. The coincidence confirmed the validity of the mode II mechanism.

References

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