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Development of elasto-plastic-creep constitutional equation for a die casting alloy and validation of thermal stress analysis

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In order to predict the residual stress in shape castings, elasto-plastic models have been used. However, these models are not able to express the recovery, which is a characteristic behavior of alloys at high temperature. This often causes over estimation of the residual stress of the castings. In this study, an elasto-plastic-creep model is developed to express the recovery of the casting during cooling. Under the conditions of some temperatures and strain rates, tensile tests were conducted to identify the creep properties. In order to validate the thermal stress analysis with the developed model, an original device, called "Equipped I-Beam Caster" was also developed to measure thermal stress and temperature of the JIS ADC12 (ISO Al Si 11 Cu3(Fe)) casting continuously during cooling. As a result, compared to the elasto-plastic model, the elasto-plastic-creep model predicts more accurately not only the thermal stress during cooling but also the residual stress.

Keywords: *Thermal stress analysis, Constitutive equation, Residual stress*

1. Introduction

In order to predict the residual stress in shape castings, elasto-plastic constitutional equation (E-P) models have been used. However, these models are not able to express the recovery, which is a characteristic behavior of alloys at high temperature. This often causes over estimation of the residual stress of the castings.

In this study, an elasto-plastic-creep constitutional equation (E-P-C) model is developed to express the recovery of the casting during cooling.

In order to validate the thermal stress analysis with the developed model, an original device was also developed to measure thermal stress and temperature of the ADC12 casting continuously during cooling.

2. Measurement data for validation

In order to validate the thermal stress analysis with the developed model, an original device, called "Equipped I-Beam caster" (Fig.1) was also developed to measure thermal stress and temperature of the casting continuously during cooling.

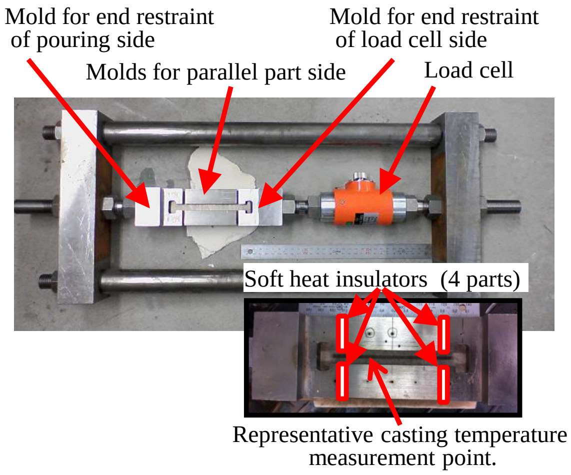

Fig. 1 Appearance of Equipped I-Beam Caster.

Cavity in this device is designed as I-shape. Both ends of the cavity, which are T-shaped, are constrained in metal molds for end restraint. To the frame, one metal mold is connected directly and the other is connected through 30kN load cell. Soft heat insulation with a thickness of 2mm is installed in a gap between end restraint metal mold and mold for parallel part side of cavity. This allows the metal molds on both ends to displace as the casting shrinks in the cavity. The size of parallel part of the cavity is 10mm x 10mm x 100mm. The end restraint metal molds are made with JIS SUS430 (ISO X6Cr17). The molds for parallel part side are made with JIS SUS304 (ISO X5CrNi18-10). Block-shaped insulations with a thickness of 15mm cover the upper and lower surfaces of the cavity.

With the device, the displacement of the metal molds on the ends and the load on the load cell were measured during cooling process of the ADC12 casting. The temperatures of the casting and the metal mold were also measured.

3. Identification of constitutional equation model

An E-P-C model was developed to express the recovery of the casting during cooling.

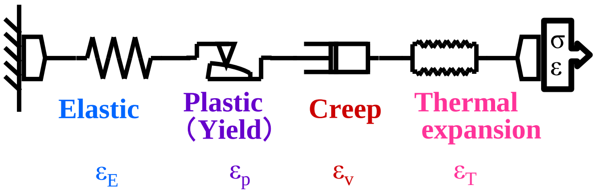

Fig.2 One dimensional schema drawing of E-P-C model.

Fig.2 shows one dimensional schema drawing of E-P-C model. σ is stress and ε is total strain which is sum of strains by elastic(ε_E), plastic(ε_p), creep(ε_v), and thermal expansion(ε_T).

Under the conditions of various temperatures and strain rates, tensile tests were conducted to measure the plastic and creep properties. The specimens of ADC12 were fabricated by the PF die casting process. After the solution treatment at 450°C for 3.6 ks, for removing the natural aging, the specimens were cooled to the aimed temperatures. In the identified E-P-C model, creep contributes to deformation above 250°C and plasticity does not work above 300°C.

For a comparison, two E-P models, dependent and nondependent on strain rate respectively, were identified from the results of the same test.(Each of them is called E-P<DSR> , E-P<NDSR>)

4. Thermal stress analysis

For validation of developed model, load history calculated with thermal stress analysis with boundary conditions based on actual temperature and actual displacement, was compared with actual load history.

Temperature history data necessary for the thermal stress analysis was created with filling analysis and solidification analysis under the actual casting conditions. To match temperature history from the analyses with the actual measured temperature history, interfacial heat transfer coefficient was adjusted in filling analysis and solidification analysis.

Then the thermal stress analysis was performed using the constitutional equation models. The temperature history data acquired in the solidification analysis was used for the constraint condition of the analysis. The measured displacement of the end restraint metal molds of equipped I-Beam caster was also used for same purpose.

5. Result of validation

Fig.3 shows a comparison between the calculated load history and the actual measured load history. Load histories were calculated in both analyses with considering and without considering the recovery. The case in which the recovery is taken into consideration by E-P-C model shows a smaller load error and its output is closer to the actual measured value. Compared to the E-P models, the E-P-C model predicts more accurately not only the thermal stress during cooling but also the residual stress.

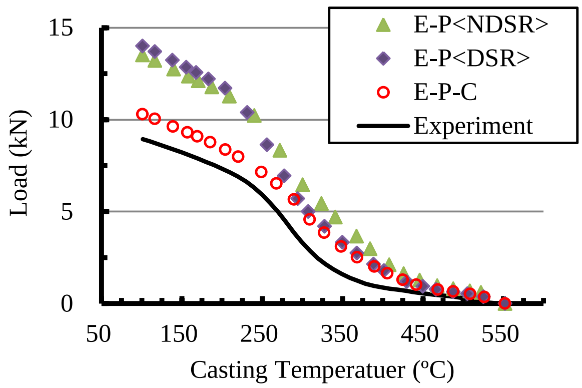

Fig.3 Comparison of the simulated and the measured thermal load during cooling.

6. Conclusion

In order to determine prediction accuracy in a thermal stress analysis of ADC12 casting, the outcomes of experiment with equipped I-Beam caster and the result of the thermal stress analysis employing the constitutional equation model in which the recovery was considered were continuously compared by the load of the casting.

It is found that the use of the constitutional equation model considering the recovery leads to a higher prediction accuracy.

References

[1] Yuichi Motoyama : Reports of the 161st Japan foundry Engineering Society meeting (2012) 21,22

[2] Hidetoshi Shiga, Takeshi Sato, Hiroshi Kambe, Yuichi Motoyama, Makoto Yoshida : Journal of Japan foundry Engineering Society 7 (2015) *pp*.453-459