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Dynamic measurements of the load on gray cast iron castings and contraction of castings during cooling in furan sand molds

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ABSTRACT

After JIS FC300 (almost identical to ASTM 45) gray cast iron was cast in a furan sand mold, both the load on the casting from the sand mold and contraction of the casting were measured dynamically from the beginning of solidification to 200 °C. During solidification, the cast iron casting received compressive load from the sand mold attributable to expansion of the casting. After solidification, the load on the casting and the contraction of the casting increased linearly with cooling. During A1 transformation, the load on the casting was relieved because of the casting expansion. After the A1 transformation, the load on the casting and the contraction of the casting increased linearly with cooling again. When the load on the casting reached approximately 13 kN, the load stayed constant, probably because of the sand mold fracture.

1. Introduction

Residual stress and warpage have been severe defects for products made by sand casting, such as cylinder heads or machine tool beds. T.S.32 (1952) identified these defects as caused by the following factors.

1) Temperature difference in a casting during cooling.
2) Phase transformations in the solid state during cooling.
3) Sand mold restraint on the contraction of the casting during cooling.

This study specifically examines the latter: sand mold restraint on the contraction of casting.

In recent years, prediction of defects has been attempted using finite element method (FEM) thermal stress analysis, which incorporates consideration of the sand mold restraint on the contraction of the casting. Ahmed and Chandra (1997) performed thermal stress analyses for an I-shaped copper alloy casting. This study demonstrated numerically that mechanical properties of sand mold affect the residual stress of the casting. Metzger et al. (2001) and Chang and Dantzig (2004) reported a model that expresses the mechanical interaction between the sand mold and the casting. This method shortened the analysis time and obtained similar results to those obtained using a previous FEM thermal stress analysis. In addition, Lin et al. (2009) predicted the hot tear position of the steel casting using the method described by Baghani and Davami (2014) obtained the mechanical properties of a sand mold by uniaxial compression test, and presented elastic and elastoplastic constitutive equations. They performed FEM thermal stress analyses for an H-shaped steel casting and verified results of the analyses by measuring the residual stress of the middle path. They revealed that the elastoplastic model is more accurate to predict residual stress than the elastic model is.

In this way, previous studies have been conducted to predict the residual stress, distortion, and hot tear of the casting by considering the restraint force from the sand mold. However, these analyses were verified by measured results only after cooling. As in studies described above, experimentally obtained results were not measured dynamically from solidification to room temperature. Results were not compared those of analyses dynamically. Consequently, it

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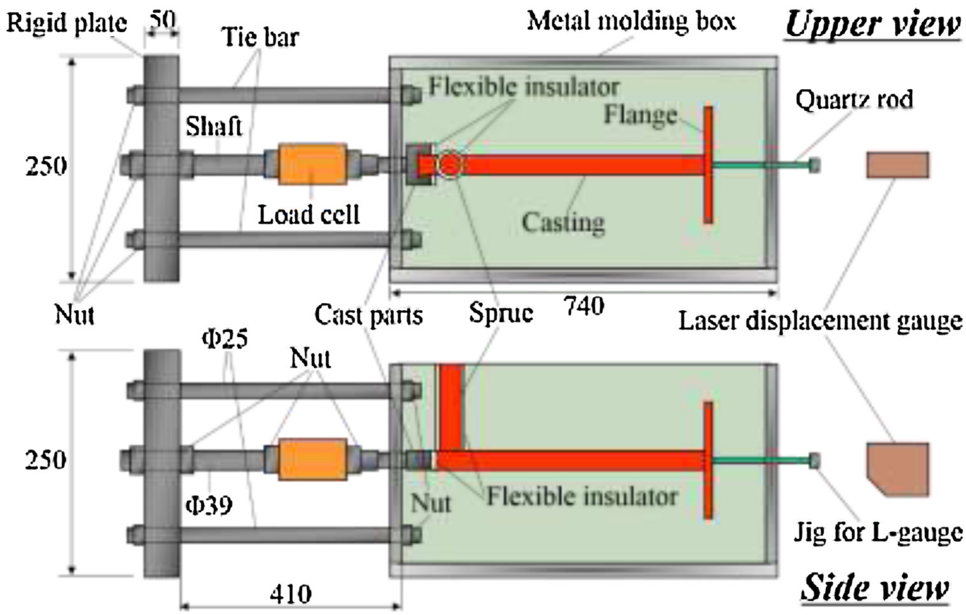

Fig. 1. Schematic of the device for measuring the load on casting and contraction of the casting.

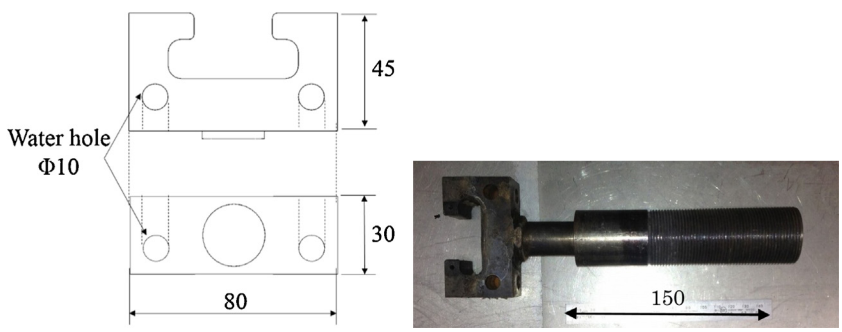

Fig. 2. Schematic illustration and photograph of the cast part.

remains unclear whether the mechanical properties and constitutive equations of the sand mold used in previous studies can express the experimentally obtained results dynamically.

Motoyama et al. (2012a) developed a device for measuring the restraint force from the sand mold and the contraction of an aluminum alloy casting dynamically. Then, Motoyama et al. (2012b) measured the values of an aluminum casting from solidification to 50 °C using the developed device. Motoyama et al. (2013) and Inoue et al. (2013) examined the validity of the mechanical properties and constitutive equations of sand mold by comparing the experiments and analyses dynamically.

However, residual stress and warpage have presented severe problems not only for aluminum castings but also for cast iron castings, such as cylinder heads or machine tool beds. The cast iron castings expand during solidification and A1 transformation, unlike aluminum castings. No previous studies have measured how cast iron castings receive the load from the sand mold or contract during phase transformations.

In this study, based on the method of Motoyama et al. (2012b), both the restraint force from a furan sand mold and the contraction of the cast iron casting were measured dynamically with improved devices for cast iron casting. Finally, we discussed the expansion during the phase transformations and mechanical interaction between the sand mold and the casting.

2. Experimental procedures

The restraint force from the sand mold and the contraction of the cast iron casting are measured using a new improved device based on the method of Motoyama et al. (2012b).

Fig. 1 portrays a schematic illustration of a device for measuring the load on casting and the contraction of the casting dynamically. The end of the casting opposite side of the flange was fixed by a cast part (Fig. 2) after pouring. At the same time, a quartz rod was cast-in (Fig. 1). Longitudinal contraction of the casting was obtained dynamically by measuring the displacement of the quartz rod using a laser displacement gauge. Simultaneously, the restraint force reacting on the flange of the casting was measured dynamically using a load cell (100 kN maximum load). Experimental values were obtained at 2 Hz from the start of solidification (approx. 1210 °C) to 200 °C (approx. 8000 s).

The cast part, made of JIS SUS 430 steel (ASTM 430 steel), had a cooling system for the prevention of thermal expansion of the cast part (Fig. 3). Cooling water was supplied (ϕ10 mm), and exhausted through the cast part. The flow rate was approximately 1.0 L/min.

For this study, the full mold casting method was used. Fig. 4 shows the geometry of the casting and the thermocouple locations. The flange was 90 mm square. Temperatures of the casting (A, inside of the cast part; B, center of the casting; C, flange (Fig. 4)) were measured using ungrounded type N thermocouples (stainless steel