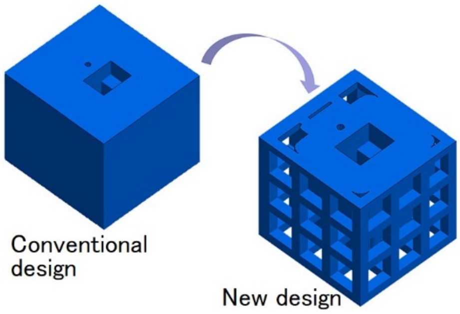
Optimum Mold Structure Design Technology Utilizing Sand Mold Additive Manufacturing



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The material characteristics of sand castings are affected by the cooling velocity during casting. Conventionally, the cooling velocity could not be increased because of the limited mold structures, and manufacturing of high strength and large/thinned castings had its limit. On the other hand, additive manufacturing technologies have been improved in recent years, and it is becoming possible to manufacture molds with a high degree of freedom in shape. By utilizing these technologies, Mitsubishi Heavy Industries, Ltd. (MHI) developed a mold design technology that allowed production of castings having characteristics that could not be obtained in the past. This report describes the details and application effects of the developed technology.

1. Introduction

In recent years, additive manufacturing technologies have been improved and the degree of freedom in mold shape has been increasing. **Figure 1** shows the outline of the mold manufacturing process using the additive manufacturing technology. First, sand, which is a mold material, is spread by one layer on the table and a binder is printed to the parts to be solidified. Next, the table is lowered by one layer and a new sand layer is spread. These steps are repeated to laminate sand layers. After the completion of the lamination, sand in the non-binder printed portions is removed from the molding body and a mold is completed. By this process, a sand mold having a shape that could not be easily formed by the conventional method can be made.

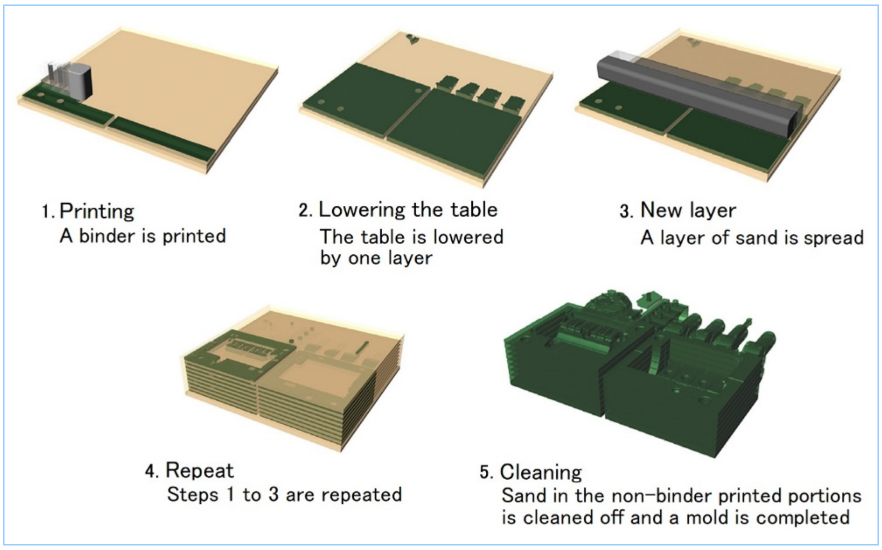

Figure 1 Outline of the sand mold additive manufacturing process[(1)]

It is considered that when this technology is used, it becomes possible not only to prevent casting defects but also to control the cooling velocity during casting by manufacturing a mold

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having an optimal shape according to the casting shape, realizing increased strength and thinning of castings. MHI did not have a mold design technology for that purpose. In addition, although the additive manufacturing technology has the above-described characteristics and further eliminates the process of making wooden molds, significantly reducing the lead time, it has not been fully utilized because it requires special sand having a high unit cost, and so on.

Accordingly, we developed a mold design technology for increasing the cooling velocity of castings while reducing mold damage and casting defects. We also conducted prototype tests for castings and evaluated the effect of reducing the special sand and the possibility of increasing the hardness of castings when the additive manufacturing molds are applied.

2. Development of mold design technology

MHI has developed the FT-Hollow software as a design tool in collaboration with Tsinghua University. **Figure 2** shows the flow chart of the mold design. First, a 3D shape model representing a product shape and the parts designed for casting such as a feed head and a sprue runner are prepared. Next, the kind of material and the major thicknesses of a casting to be produced are set, and according to the settings, an initial design model for the mold shape is output with reference to the mold thickness data shown in **Figure 3**. Figure 3 shows the relationship between the casting thickness and the required mold thickness for cast iron and aluminum alloy as an example. The mold temperature which varies by the casting thickness is obtained through analysis and the required mold thickness is determined from the actual measured values of the varying mold strength which varies by the mold temperature. The mold strength is affected by the solidus temperature in addition to the specific gravity of the casting material.

When the actual casting conditions are input for the output initial design model, the presence or absence of mold damage during a casting test is evaluated based on the hydrostatic pressure, the buoyancy and the calculated residual strength of the mold obtained from the heat-transfer analysis result. The mold strength is temperature dependent as shown in **Figure 4**, and as the temperature becomes higher, the strength tends to become lower. Therefore, the mold strength is evaluated in consideration of the temperature change during a casting test and if necessary, readjustments such as increase of the mold thickness are conducted so that the mold strength can be secured. When this design flow is repeated, a thin-walled mold that is not damaged during a casting test can be designed.

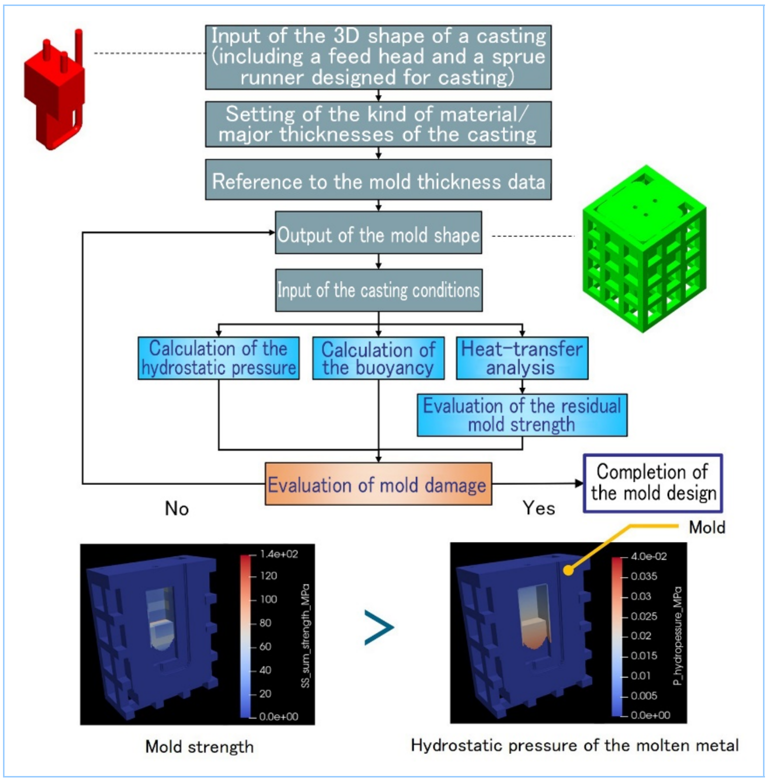

Figure 2 Flow chart of the mold design

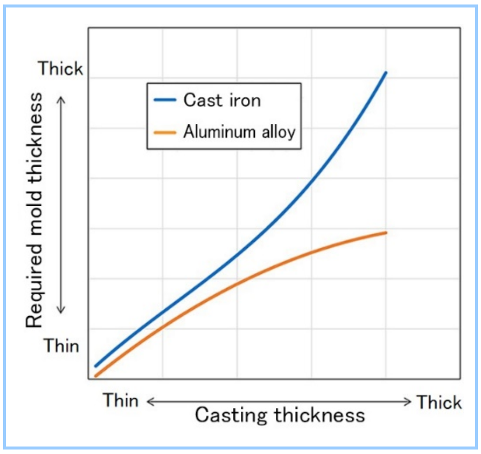

Figure 3 Casting thickness and required mold thickness

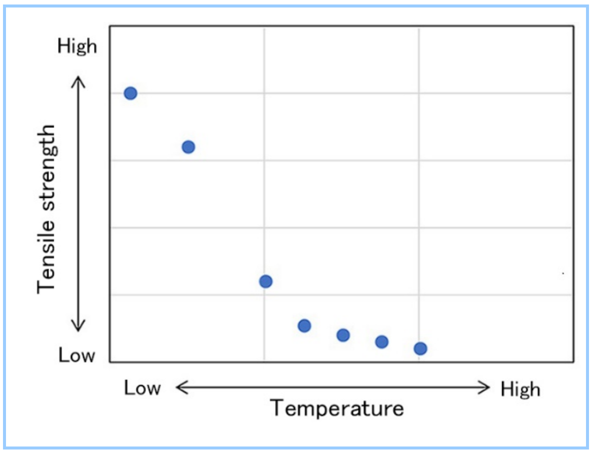

Figure 4 Temperature dependency of mold strength

3. Trial design of additive manufacturing sand molds

In order to evaluate the appropriateness of the design flow, we made a trial design of molds for a casting having a simple shape. **Figure 5** shows the casting shape and the designed mold shapes. Nodular graphite cast iron (FCD450) was applied as the casting material.

The block mold has a conventional mold shape. The lattice mold is designed according to the flow in Chapter 2, in which sand is eliminated from parts except the parts requiring sand in view of strength, and it uses less sand than the block mold. In order to conduct comparative verification in the casting test described later, we also output an excessively thinned lattice mold which was assumed not to resist the hydrostatic pressure and buoyant force of the molten metal.

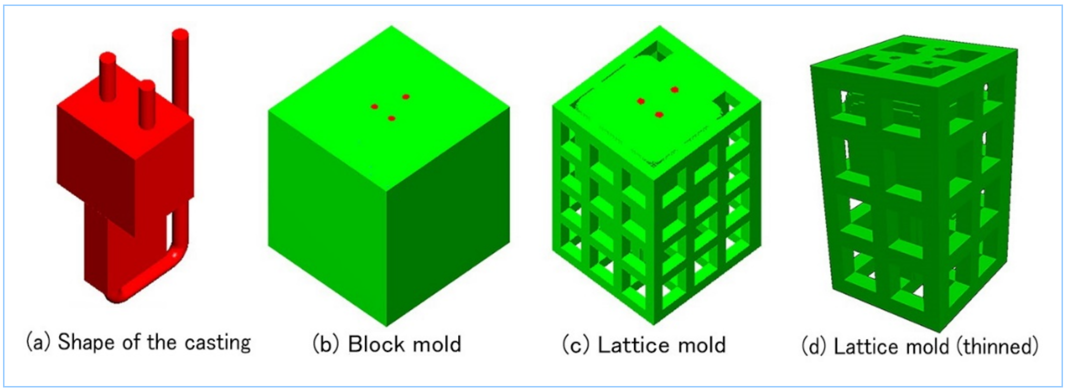

Figure 5 Shapes of the casting and the molds for trial production

Figure 6 shows the results of the damage assessment of the designed lattice mold. We conducted a heat-transfer analysis of the lattice mold using casting analysis software and confirmed that most of the casting surface was solidified in about 30 minutes, and at the same timing, the damage evaluation was conducted. As a result, it was evaluated that in the area having the maximum hydrostatic pressure, the residual strength value of the mold was high and there was no mold damage risk. We also conducted the same evaluation at other timings and confirmed that at any timing, the residual mold strength was higher than the hydrostatic pressure and the buoyant force and no mold damage would occur.

The sand usage reduction effect of the molds designed according to this flow is as shown in **Table 1**. The usage of sand can be reduced by 62% and the mold material cost can be also reduced in the same way.

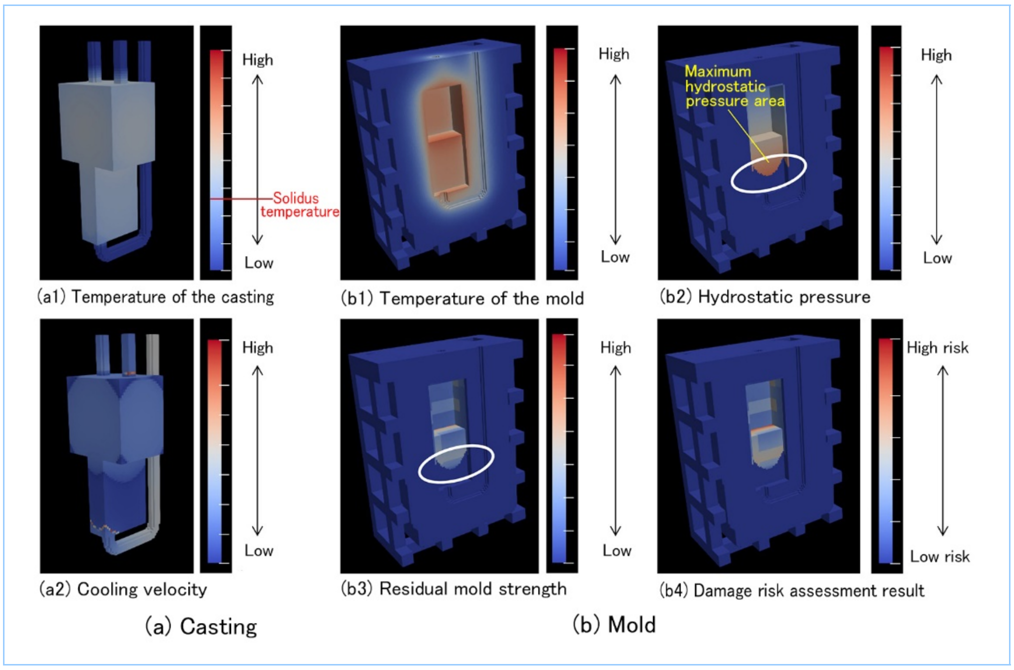

Figure 6　Assessment result of the casting and the mold during the casting test (about 30 minutes after pouring of the molten metal)

Table 1　Sand mold weight and sand mold weight reduction rate

Kind of mold	Mold weight (kg)	Sand mold weight reduction rate (%)
Block mold	665	0
Lattice mold	251.6	62%
Lattice mold (thinned)	75.6	89%

4. Casting test using additive manufacturing sand molds

We actually conducted a casting test using the output mold shapes. In order to evaluate the difference in the cooling effect between molds having different designs, we also performed forced cooling by air blow to a specific area of each mold. In the same way as in Chapter 3, nodular graphite cast iron (FCD450) was applied as the casting material.

Figure 7 shows the external appearances of the molds after the pouring of the molten metal. We confirmed that casting could be performed without spilt molten metal not only by the block mold but by the lattice mold (the red hot part on the top face of the mold is the molten metal that overflowed the run-off part at the time of pouring). The intended shape of casting was obtained. On the other hand, with the excessively thinned lattice mold, there was no abnormality immediately after the pouring of the molten metal, but a leakage of the molten metal occurred within 10 minutes after pouring. This was a phenomenon predicted by the mold damage evaluation. It is considered that the temperature of the external surface of the mold increased, the binder was lost, the residual mold strength was reduced and the mold could not resist the hydrostatic pressure of the molten metal. From this result, it can be said that the output lattice mold has a shape securing the required mold strength and also reducing the sand mold weight.

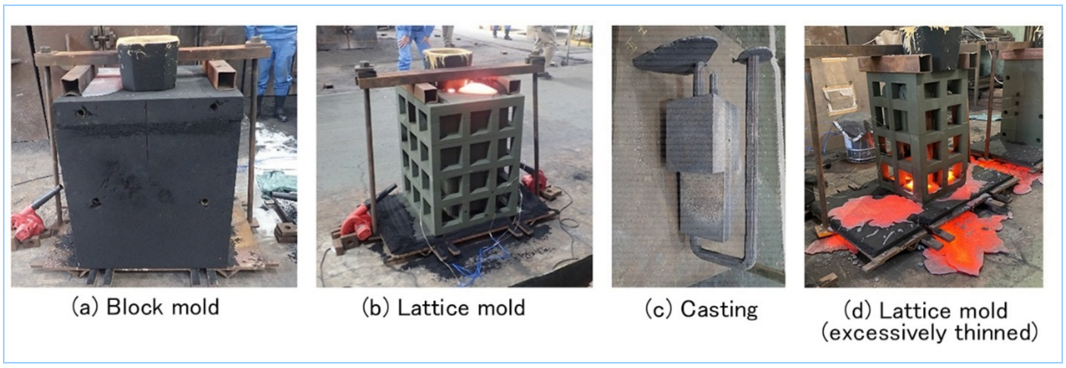

Figure 7　External appearances of the molds after the pouring of the molten metal

Figure 8 shows the hardness of the casting surface at the force-cooled portion on each of the block mold and the lattice mold. No increased hardness was observed at the force-cooled portion of the block mold, while the lattice mold showed the tendency of increased hardness by forced cooling and its hardness increased by 6% compared to that of the block mold. That is, we could confirm that the increase of the cooling velocity in addition to the thinning of the mold could increase the strength of the casting.

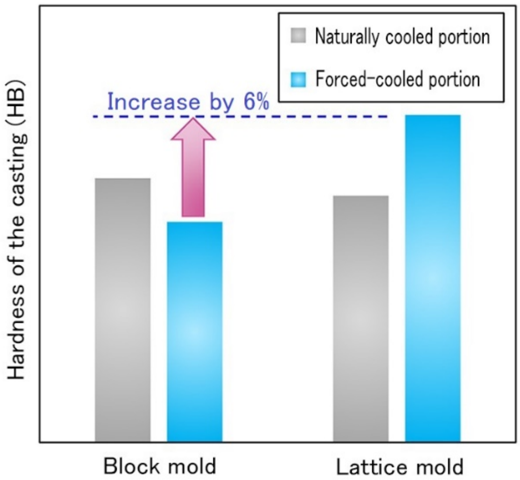

Figure 8 Evaluation result of the hardness of the forced-cooled portion

5. Conclusion

We developed a mold design technology that allowed casting without mold damage and made efforts to increase the strength of castings produced by the additive manufacturing technology. By appropriately thinning a mold and forming it into a lattice shape, we could reduce the usage of expensive special sand for additive manufacturing by 62%, and by applying external cooling by air blow or the like, we achieved the increase of the casting strength by 6%. In the future, we will promote application of this technology to small-lot and complicated casting shapes which MHI Group deals with.

References

(1) Documents provided by ExOne