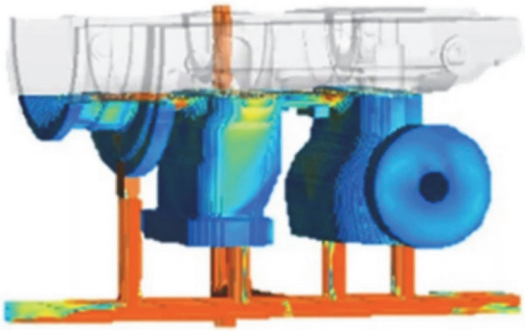
Development of Innovative Casting Technology for Realization of Decarbonized Society



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Mitsubishi Heavy Industries, Ltd. announced its "MISSION NET ZERO" in October 2021, aiming to reduce CO_2 emissions from its business activities to net zero by 2040. A casting sector of Mitsubishi Heavy Industries, Ltd. emit a large amount of CO_2 in the melting process, and to reduce the CO_2 emissions, it is necessary to reduce the amount of risers which do not become the final product. This report describes the development status of an innovative casting technology that ensures casting quality without the use of risers and the effects of its application.

1. Introduction

Solving the global warming issue is an important task for humankind. The Japanese government declared that it will aim to become "carbon neutral" to reduce the nation's overall greenhouse gas emissions to zero by 2050. In line with this declaration, Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) has also set a goal of achieving net-zero direct CO_2 emissions and net-zero indirect CO_2 emissions from electricity consumption by 2040.

The casting sector also sees increasing momentum to suppress CO_2 emissions, and efforts have been made in an accelerated manner to reduce energy consumption during manufacturing, use waste heat effectively, and utilize renewable energy sources. **Figure 1** shows an example of the breakdown of CO_2 emissions in the casting process (excluding heat treatment) for cast steel products. As shown in this figure, CO_2 emissions from the melting process, in which raw materials are heated to about 1,600°C, account for about 40% of the total emissions. **Figure 2** shows the component breakdown of the casting weight. Approximately 40% of the molten metal is used for the risers, which do not become the final product. The riser is provided to prevent shrinkage cavities, which occur in the area of final solidification of the metal, from occurring in the product. Therefore, the riser is designed to have a larger modulus (casting volume/casting surface area) than the product and requires a large melting weight. Since the riser can be reused as a melting material and its impact on material costs is small, it has been used for many years as a means of reducing shrinkage cavities. However, to respond to the recent needs to realize a decarbonized society, MHI has been working on the development of an innovative sand casting technology to produce high-quality castings without the use of risers. This report introduces on this development.

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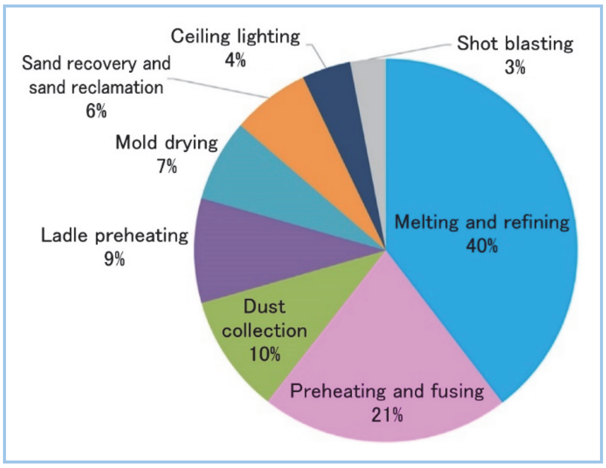

Figure 1 Example of CO_2 emissions breakdown in casting process

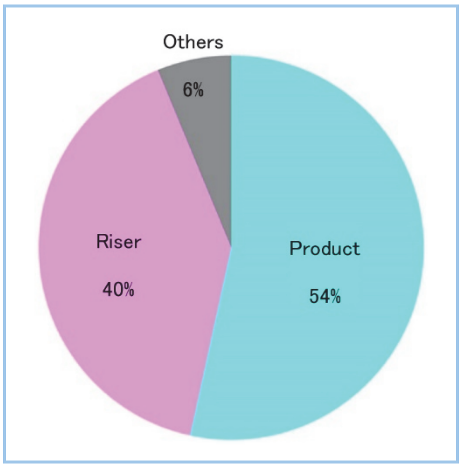

Figure 2 Component breakdown of casting weight

2. Development of innovative sand casting technology

2.1 Conventional casting method

Figure 3 shows a conventional casting plan for a simple shape sand mold casting of cast steel as an example. The production of castings requires a sprue system (sprue, runner, and ingate) for pouring molten metal, as well as risers and chills to suppress shrinkage cavities in the product. This section describes the design method of a casting plan that shows the shape and arrangement thereof. Note that the design method for runner systems, which is not an object of this report, is omitted here.

First, the dimensions of the sand mold that forms the product take into account the shrinkage of the material. **Figure 4** shows the rate of shrinkage accompanying the decrease in temperature after solidification (reaching the solidus temperature) for a typical steel material as an example. Reflecting this, the sand molds are designed so that the dimensions at room temperature are the target values.

Next, the riser is designed in consideration of the shrinkage that occurs before the casting solidifies (reaches the solidus temperature). In the temperature range where the solid and liquid phases coexist, the solid-phase material shrinks as the temperature drops, causing cavities, but molten metal with fluidity flows into the cavities and suppresses the shrinkage cavities. Under atmospheric pressure, molten metal flows in the direction of gravity, so it is common to aim for continuous solidification from the bottom to the top (directional solidification). To achieve this, risers designed to have a size so that it solidifies later than the product section are placed above the product section, taking the modulus into consideration. In addition, in areas where the solidification occurs slowly, a chill having a higher thermal conductivity than that of sand is embedded in the sand mold to cool the area forcibly. **Figure 5** shows the results of solidification analysis for different casting methods with different-size risers. As shown in this figure, it can be seen that to avoid the position where the last solidification occurs and shrinkage cavities are likely to occur, that is, the position of the highest temperature, from existing in the product section, a larger riser is required.

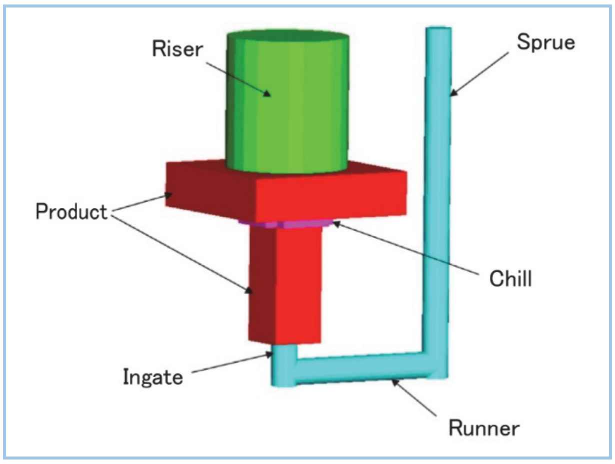

Figure 3 Casting plan

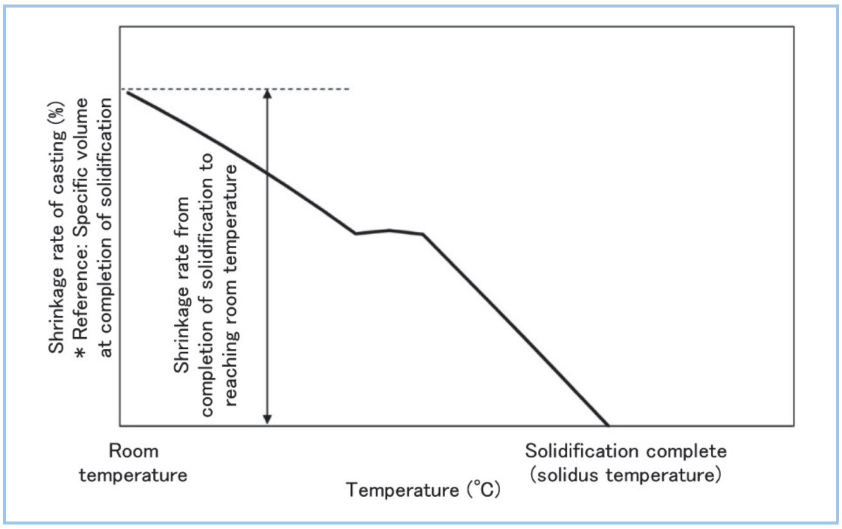

Figure 4 Casting shrinkage rate from solidification completion to reaching room temperature

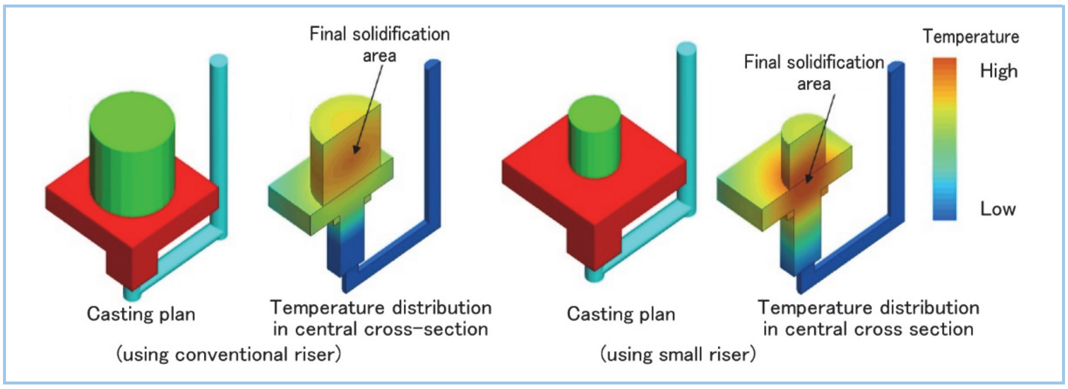

Figure 5 Temperature distribution at solidification

2.2 Innovative casting technology

MHI has developed an innovative casting technology that does not use any risers, unlike the conventional technology. This section describes the design procedure of the casting plan using this technology.

(1) Sand mold design for product section

As before, the mold is designed considering the amount of shrinkage from the completion of solidification to reaching the room temperature.

(2) Casting posture

The casting posture is set so that the final solidified area is positioned in the upper part of the mold, with the results of solidification analysis on the shape of the product referred to.

(3) Measure against shrinkage cavities in state where liquid phase remains

Figure 6 shows the casting shrinkage rate with respect to the temperature from the pouring of the molten metal to the completion of solidification. The shrinkage is determined by the material of the casting. The basic concept of the innovative casting technology is to provide additional volume corresponding to this shrinkage on the top surface of the product to replenish molten metal to the product section. To continuously replenish molten metal, chills and heat insulators are used. Although it partly depends on the shape of the product, directional solidification is realized by placing large chills at the lower part of the product and small chills at the upper part of the product. With this method alone, supplying molten metal from the additional volume section is difficult as a result of a sharp temperature drop of the upper surface of the additional volume section, which is exposed to the atmosphere. To avoid this, a heat-insulating material with a heat-generating function is placed on the top surface.

This innovative casting technology involves the design of sand molds to which the additional volume corresponding to solidification shrinkage is incorporated. However, this is to deal with the density change accompanying the temperature drop of the material, and the melting weight is not increased because of the additional volume section. In other words, a casting removed from the sand mold has the shape of the final product, except for the sprue system.

This technology requires proper arrangement of multiple types of chills without the use of risers. Casting simulation is used in the design. To put this technology into practical use, simulations that can reproduce phenomena with high accuracy as well as advanced on-site controls for suppressing manufacturing variations in the casting process, which involves a lot of human work, are needed. MHI successfully provided them to realize the practical use of this technology.

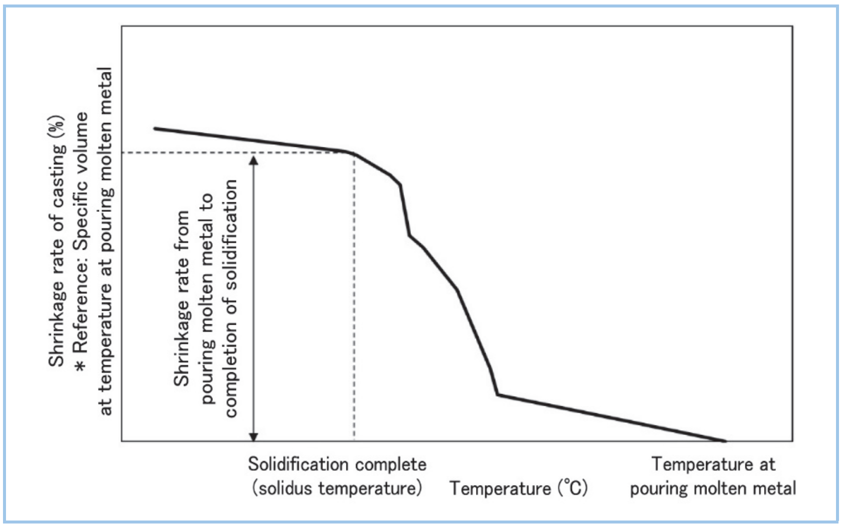

Figure 6　Casting shrinkage rate with respect to temperature from pouring molten metal to completion of solidification

3. Applicability verification of innovative casting technology

Toward the practical application of this method, prototypes of several-ton-class castings shown in **Figure 7** were made using the conventional and innovative casting methods. The innovative casting technology was confirmed to be able to ensure an equivalent quality as the conventional method by evaluating shrinkage cavities in the casting analysis, and was then verified to generate no internal defects as a result of this trial production verification. This method increased the number of chills used by 6%, but reduced the melting weight by 40% as shown in **Figure 8** due to the reduction in the amount of risers. The elimination of the need for sand molds to form the risers resulted in a reduction of time required for molding work and the amount of resin and hardener used, which are secondary effects, other than melting energy.

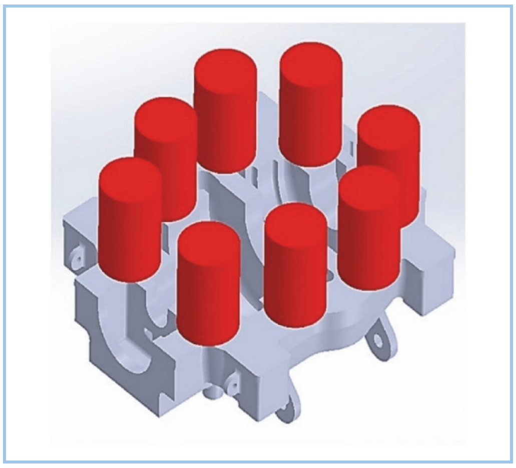

Figure 7 Part for applicability verification of innovative casting technology (Product and risers used for conventional technology are shown)

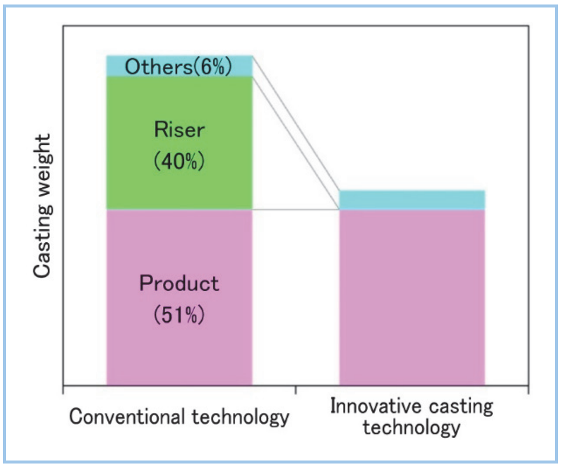

Figure 8 Breakdown of melting weight

4. Conclusions and future prospects

MHI developed an innovative casting technology that significantly reduces melting energy by reducing the melting weight. It was confirmed that this technology can reduce the melting weight by 40% and reduce power consumption and CO_2 emissions during melting by 40%. This method has been applied on a full scale to actual castings, and is planned to be expanded to multiple parts in the future. MHI is also promoting the application of automatic plan design technology using machine learning to reduce the manpower load in designing the optimal placement of chills, thereby contributing to the realization of a decarbonized society in the future.