Lineup of Mold Powder Products

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Abstract

Mold powder has many roles in the continuous casting process, including thermal insulation of the molten steel surface, protection of the molten steel from oxidation, lubrication between the steel shell and the mold, and controlling heat removal in the mold. Mold powder requires appropriate design given certain casting conditions. This report introduces our wide variety of mold powder products.

1. Introduction

Mold powder is added to the surface of molten steel and melted by heat from the molten steel. Melted powder liquid flows between the mold wall and the solidified steel shell. The roles of mold powder are as follows:

① Protection of the molten steel surface from oxidation by air
② Thermal insulation of the surface of the molten steel
③ Absorption of non-metallic inclusion that float to the surface of the molten steel
④ Lubrication between the mold and the solidified steel shell
⑤ Heat removal control between the mold and the solidified steel shell

There are many casting conditions which must be considered such as steel grade, mold size, casting speed, and so on. The properties needed in a mold powder vary with various casting conditions. Suitable mold powder must be used for each casting condition. We have developed many mold powders for many casting conditions. This report introduces our wide variety of mold powder products.

2. High Speed Casting Mold Powder

High speed casting improves productivity of continuous casting. At present, conventional slab casters can achieve 3.0m/min maximum casting speeds and thin slab caster can achieve over 6.0m/min[1)-3)].

It is necessary for high speed casting mold powders that can cast without breakout even though the thickness of the solidified steel shell becomes thinner and weaker as higher casting speed is achieved[4),5)]. Mold powder for high speed casting requires properties that provide sufficient heat removal to form sufficient thickness of the solidified steel shell in the mold and good lubrication between the solidified steel shell and the mold wall in order to prevent breakout. As shown Fig. 1, the consumption of mold powder tends to decrease with increasing casting speed, and the risk of sticker type breakout will increase due to lack of lubrication. Sufficient lubrication is maintained by designing a mold powder which does not to have excess viscosity or crystallization temperature in order to increase powder consumption.

The risk of wash through type breakout also will increase with thin solidified steel shell during high speed casting: therefore sufficient and uniform heat removal in the mold is necessary.

The air gap formed between the mold and the solidified steel shell at the bottom part of the mold prevents heat removal. In order to prevent the air gap and increase the heat removal, we developed a mold powder that contains Li_2O and has the appropriate basicity for improving flowability at lower temperature in the bottom part of the mold.

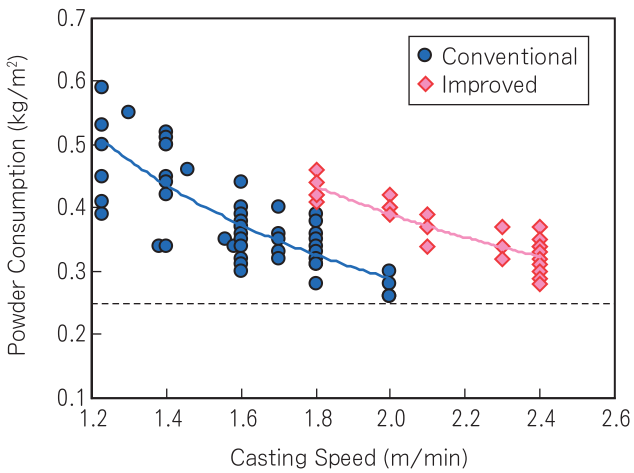

Fig. 1 Effect of casting speed on mold powder consumption.

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Furthermore, molten steel level fluctuation sometimes occurs during high speed casting due to unsteady bulging of the slab[6),7)]. Mold powder typically had not been considered a main cause of unsteady bulging of the slab since it occurs in the secondary cooling area. In recent research, it has gradually been found that mold powder also effects the bulging. We can design mold powder that can reduce unsteady bulging by controlling the ability of the powder slag to peel away from the slab surface in the secondly cooling area[5)].

3. Ultra High Basicity Mold Powder "REVIX"

The main defects of medium and peritectic carbon steel grades are longitudinal cracking and transverse cracking on steel surface. Surface cracking of medium and peritectic carbon steel is caused by uneven solidification of the solidified steel shell due to the $\delta \rightarrow \gamma$ phase transformation with high solidification shrinkage[8)-10)]. The casting speed of conventional mold powder is limited because surface cracking tends to increase with increasing casting speed[11)]. In order to prevent surface cracking, it is important to reduce the heat removal in the mold using mold powder that has high crystallization temperature, resulting in an even solidified steel shell[12)]. However, a very high crystallization temperature reduces lubricating properties and prevents sufficient formation of steel shell thickness during high speed casting.

For reducing heat removal and maintaining sufficient thickness of solidified steel shell, we developed an ultra high basicity mold powder "REVIX"[13)]. The REVIX has a high crystallization speed property that can reduce heat removal at the meniscus, yet still make sufficient thickness of steel shell further down in the mold. The REVIX can increase crystallization speed by utilizing higher basicity than conventional mold powder. Fig. 2 shows the slag film image of the REVIX and conventional powder. The REVIX provides thicker crystal layer at the top part of the mold by the efforts of quick crystallization properties. This can reduce heat removal at the top part of the mold where cracking starts and prevent it. On the other hand, for sufficient thickness of the solidified steel shell, the REVIX is designed to have a low viscosity for filling the air gap at the bottom part of the mold, and low crystallization temperature which can provide thinner crystal layer and higher heat removal at the bottom part of the mold. These properties will provide sufficient thickness and strength of the solidified steel shell for high speed casting.

The REVIX achieves high speed casting for medium and peritectic carbon steel with stable casting operation and no incidence of surface cracking.

4. High Viscosity Mold Powder

For low and ultra low carbon steel grade which requires high quality, it is important to prevent surface defects due to powder slag entrapment into the molten steel[14),15)]. Powder slag entrapment is associated with the slag viscosity and the velocity of molten steel flow at the meniscus. It is effective to increase powder slag viscosity in order to prevent powder slag entrapment[4),14),15)]. However, increasing slag viscosity decreases powder consumption and increases the risk of sticker type breakout. For maintaining appropriate powder consumption, it is effective to increase slag fluidity by using Li_2O while keeping the slag viscosity high[4)]. As shown in Fig. 3, the addition of Li_2O reduces the slag viscosity's dependence on temperature. As a result, a high viscosity mold powder containing high Li_2O will prevent slag entrapment at the meniscus temperatures, yet still provide appropriate powder consumption due to relatively low viscosity

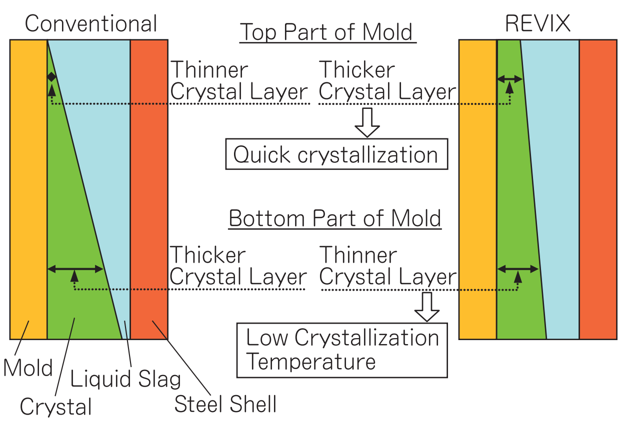

Fig. 2 Slag film image of conventional powder and REVIX.

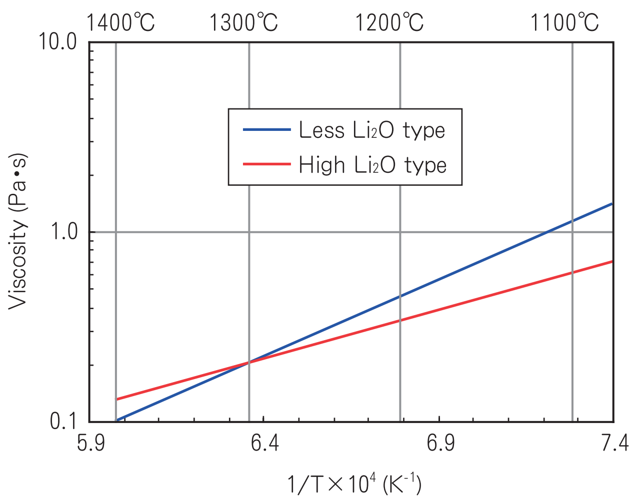

Fig. 3 Temperature dependence of viscosity of powder slag.

between the solidified steel shell and the mold wall at lower temperatures lower in the mold. Through the use of Li_2O addition, we developed high viscosity mold powder which can prevent powder entrapment and maintain sufficient consumption for stable operation.

5. Exothermic Mold Powder

Inclusion and pinhole defects on the steel surface are caused by deoxidation products, such as alumina, powder slag, and gas bubbles (such as argon) that float to the surface and are trapped under excess shell that has formed at the meniscus (called hook)[14), 16), 17)].

The cause of hook formation is insufficient temperature at the meniscus. Therefore, it is important to maintain sufficient temperature at the meniscus in order to prevent hook formation. Maintaining sufficient temperature at the meniscus can be achieved by controlling the molten steel flow with SEN design and improving the insulation properties of mold powder in order to prevent heat loss at the meniscus. Exothermic mold powder can be used for adding heat to the meniscus[4), 15), 17)–19)].

Our exothermic powder uses metal and oxidant for the exothermic reaction. The exothermic reaction of our mold powder quickly occurs and provides steady heat without leaving unreacted materials.

There are two types of exothermic mold powders: starter powder for casting start, and running powder.

Exothermic starter powder contains over 10% metal addition. As shown in Fig. 4, an exothermic starter powder quickly provides high heat and melts fast.

The effects of exothermic starter powder are shown as follows:

① High melting speed and formation of sufficient slag layer for lubrication between mold and solidified shell while start casting.

② Prevention of floaters on the surface of the molten steel, inclusions and pinhole defects

③ Reducing carbon pickup by forming sufficient slag layer and reducing carbon content of mold powder.

④ For medium and peritectic carbon steel, it can be designed to high basicity, which is similar to running powder, in order to prevent surface cracking.

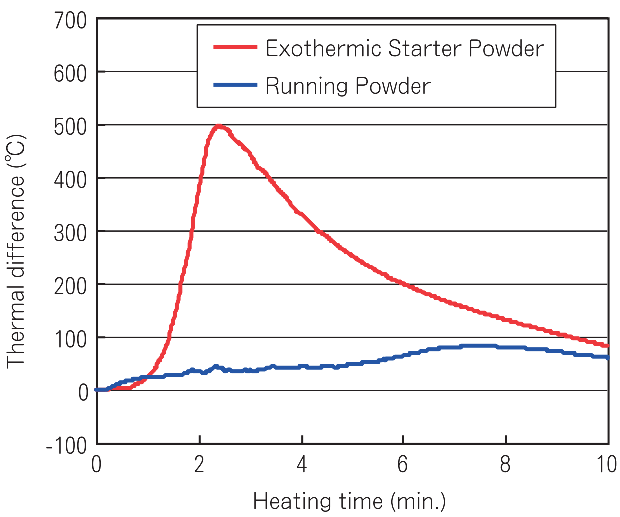

Fig. 4 Thermal difference of exothermic starter powder at 1000℃.

Amount of metal in exothermic running powder is less than that in starter powder. Exothermic running powder provides improved steel quality by utilizing exothermicity on ultra low carbon steel grades and so on.

6. Carbon Free Mold Powder

Carbon pick up from mold powder is one of the major issues when casting ultra low carbon steel grades[15)]. Blow hole is also an issue on high oxygen steel such as enameled steel. CO gas generated by the reaction between oxygen in the steel and carbon results in blow holes.

For preventing carbon pickup, it is effective to decrease the carbon in mold powder and to maintain sufficient thickness of slag layer. This will prevent contact between the molten steel and the unmelted mold powder[4)]. There are two types of carbon in mold powder: carbonate, and free carbon (such as carbon black and graphite). Free carbon is considered main cause of carbon pickup. The roles of free carbon are: preventing sintering, controlling melting speed, and providing heat by oxidation to the surface of molten steel. However, decreasing free carbon from the mold powder in order to prevent carbon pickup makes insulation properties worse. Using a mold powder with poor insulation properties, especially on ultra low carbon steel casting, forms excess steel shell (hook) at the meniscus. The hook traps floating deoxidation products and gas bubbles from the molten steel that become inclusion and pinhole defects.

We developed an exothermic carbon free mold powder. By adding metal to mold powder, this powder can keep insulation properties and control melting speed without using free carbon. Our carbon free mold powder can significantly decrease carbon pickup on ultra low carbon steel as well as improving inclusion and pinhole defects[17)].

7. Ultra High Viscosity Mold Powder “PRIOS”

For bloom, billet and beam blank casters, we developed an ultra high viscosity mold powder “PRIOS”. The PRIOS has a viscosity of greater than 1.0Pa・s, compared to conventional mold powder which has a viscosity in the range of 0.05 and 1.0Pa・s.

For ultra high viscosity ≧ 1.0Pa・s, CaO/SiO_2 is designed to have a low basicity ≦ 0.8. This basicity usually does

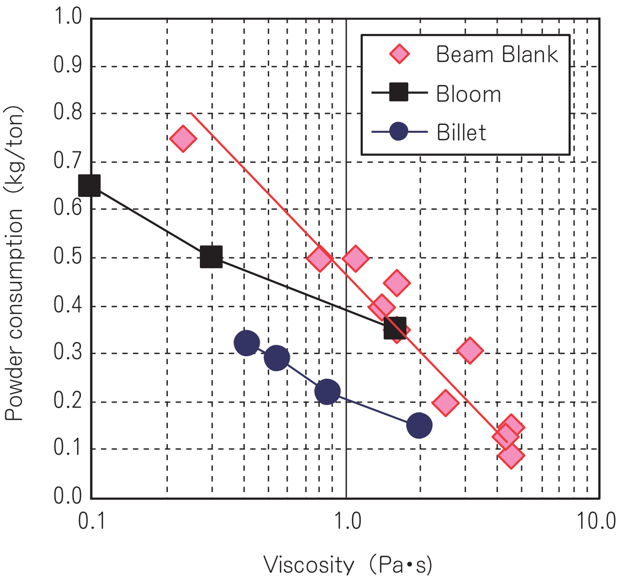

Fig. 5 Powder Consumption.

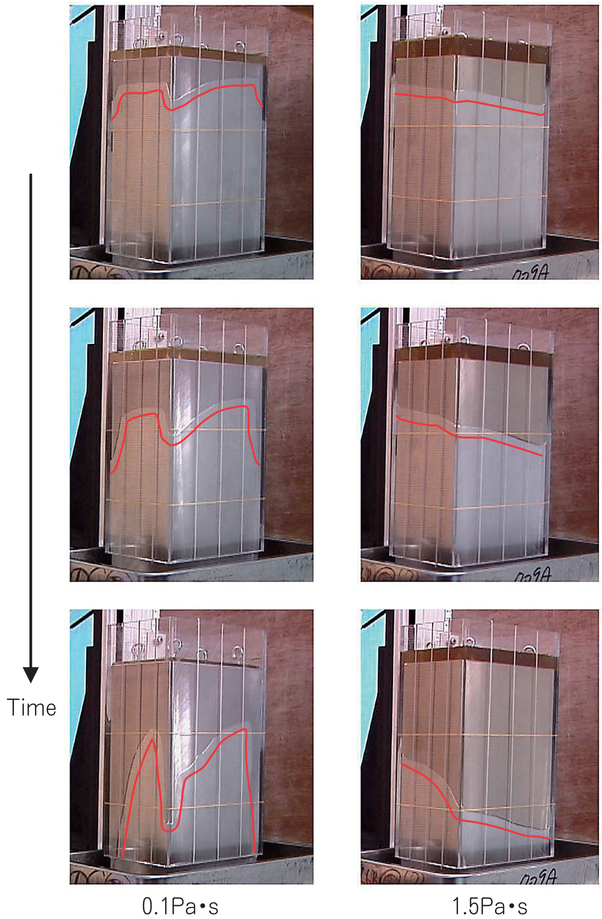

Fig. 6 Slag flow test.
Acrylic mold size : 100×150mm
Oscillation condition : 8mm×85cpm

not crystallize and provides a glassy slag film between the mold wall and steel shell. Since the ultra high viscosity glassy slag can not break easily, PRIOS does not produce sticking even though the amount of slag flow and powder consumption is much less than conventional mold powder. Fig. 5 shows powder consumption. The powder consumption of PRIOS, which has ten times higher viscosity than conventional mold powder, is reduced by approximately half. However, sticker type breakout does not occur.

Fig. 6 shows condition of different viscosity of liquid between acrylic mold (simulated caster mold), and stainless steel block (simulated steel shell). PRIOS is a high heat removal mold powder due to its completely glassy slag film. However, for ultra high viscosity properties, it can reduce cracking by uniform heat transfer due to uniform slag flow. The steel surface cast with PRIOS has good quality. Oscillation marks are shallow and uniform, without cracks.

Fig. 7 shows appearance of immersion nozzles after casting with PRIOS. PRIOS has lower erosion rate than conventional mold powders. The amount of fluorine and alkaline components (which accelerate nozzle erosion) is lower than that of conventional mold powder. PRIOS has been and continues to be used on many casters with great steel quality and stable operation[20].

Fig. 7 Appearance of SEN after casting.

8. Fluorine Free Mold Powder

In general, fluorine is added to mold powder for crucial roles that include controlling viscosity, crystallization temperature and so on. However, fluorine has negative effects of nozzle erosion[21), 22)]. Fluorine in powder slag is absorbed into the water in the secondly cooling area. This results in machine corrosion and raising the concentration of fluorine in the drain water. Therefore, the reduction or elimination of fluorine in mold powder is desired.

For fluorine free mold powder, it is possible to control viscosity of mold powder with other components such as Na_2O, Li_2O and so on. However fluorine free mold powder can not form Cuspidine crystal ($3CaO \cdot 2SiO_2 \cdot CaF_2$), which most of mold powder form. Cuspidine crystal is used for heat removal control. Therefore fluorine free mold powder is difficult to control heat removal and prevent cracking, especially on medium and peritectic carbon steel.

We have fluorine free PRIOS for small size molds, such as bloom and beam blank. This powder can prevent cracking with the properties of ultra high viscosity instead of reducing heat removal with the Cuspidine crystal, and is used on many casters[23)].

Fluorine free mold powder for low and ultra low carbon steel on slab caster is available. Due to low crack sensitivity, low and ultra low carbon steel does not required lower heat removal in the mold: therefore, Cuspidine is not needed to lower heat removal.

The use of fluorine free mold powder can solve the fluorine emission regulation which is expected in the future as well as reduce operation costs with longer nozzle life, less machine corrosion, water treatment, and so on.

9. Mold Powder for High Al Steel

Stable casting operation and improving productivity are strongly required for the casting of high Al steel, such as high Al electric steel, nitride steel and high Al peritectic steel, since multiple heats casting is difficult due to numerous operational troubles[24)-27)].

The characteristics of the mold powder is considerably changed during casting due to a large increase in the amount of Al_2O_3 and CaO/SiO_2. This is the result of the reaction of Al in the molten steel and SiO_2 in powder slag during high Al steel casting. This results in producing a large amount of rope, reducing mold powder consumption, an increasing powder slag layer thickness, fluctuation of thermocouple temperatures in the mold, and breakouts.

As mentioned above, Cuspidine is usually formed from mold powder. However Gehlenite ($2CaO \cdot SiO_2 \cdot Al_2O_3$) crystals tend to be formed if a large amount of Al_2O_3 is picked up in the powder slag. Gehlenite causes roping and fluctuation of thermocouple temperatures in the mold, since Gehlenite is a high melting point crystal compared with Cuspidine.

Due to low crack sensitivity, high Al electric steel and nitride steel do not require low heat removal in the mold. Mold powders for high Al electric steel and nitride steel are designed to have low CaO/SiO_2 and an addition of lithium material in order to avoid increasing crystallization due to increasing Al_2O_3 and CaO/SiO_2 in powder slag. As a result, these mold powders can provide stable casting operation and achieve multiple heats casting[24), 28)].

On the other hand, the high crack sensitivity of high Al peritectic steel requires low heat removal in the mold, and the use of crystal formation in the powder slag film. It is important to design mold powder which has appropriate crystallization of slag film with increases in Al_2O_3 and CaO/SiO_2. High Al peritectic steel is one of the most difficult steel grades since higher crystallization film will form due to a big slag chemistry change. This will result in the fluctuation of thermocouple temperatures in the mold, insufficient lubrication, and increasing the risk of sticker type breakout[27)]. The use of Li_2O material can control appropriate crystallization of the slag film and provide stable casting operation without cracking.

10. Dustless Fine Mold Powder "GEMINI" and White Color Mold Powder "WHITE POWDER"

Fine mold powder has advantages in insulation properties and steel quality. However it has environmental issues when casting operation due to dust and black stains on hands and clothes. We developed "GEMINI" fine mold powder[29)] which creates less dust than conventional fine powder, and white or gray colored fine mold powder "WHITE POWDER"[30)].

Using technology that can adhere the very small particles, the GEMINI reduces dust while mold powder is added to the mold, and also reduces the dust created while casting with argon gas. Fig. 8 shows the results of dust test for the GEMINI and conventional powder. Dust ratio of the GEMINI is greatly lower than that of fine mold powder. In actual casting, the consumption rate of the GEMINI decreased by 6～30% due to the reduction of dust loss. The GEMINI has been and is currently being used many casters.

Carbon black, which is used for maintaining melting speed control and preventing rope, is a source of the blackness of conventional powder. We developed "WHITE POWDER" which can control melting speed and prevent rope without carbon black. For this technology, we can make a fine powder with a white or gray color. Fig. 9 shows the results of a melting properties test of the WHITE POWDER in a high frequency induction furnace. The WHITE POWDER has same melting properties and is able to control the melting speed as well as a conventional powder. The WHITE POWDER has been

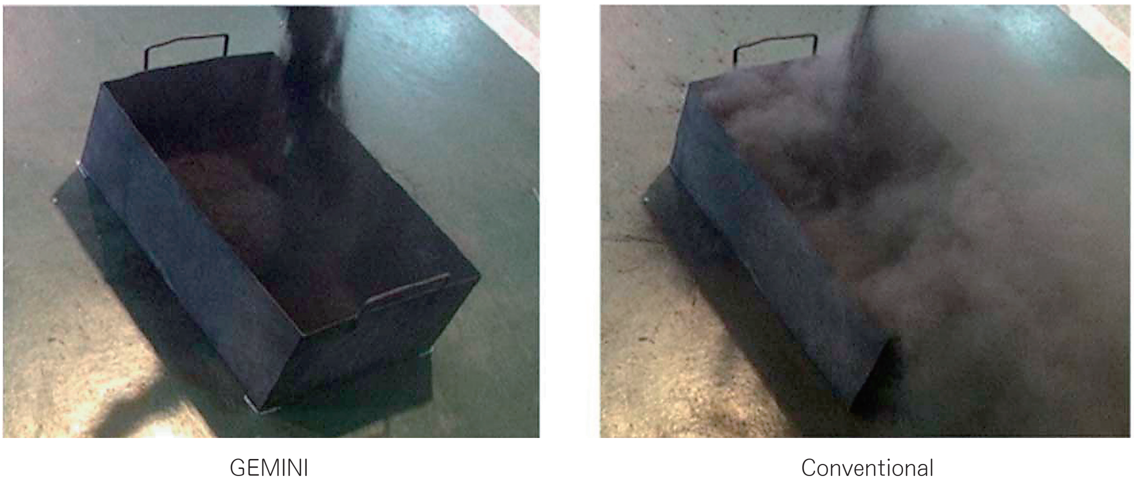

Fig. 8 Comparison of dust.

used on many casters resulting in an improved working environment.

The GEMINI and WHITE POWDER improve working environment with good quality results since they are fine mold powders and have the same insulation properties as the conventional fine powders. We are also able to combine the GEMINI and WHITE POWDER technologies in any mold powder application.

11. Conclusion

Our wide variety of mold powder products and technologies were described in this report. The demand of high steel quality is increasing with continuous improvement of casting technologies. We are continuing to develop high quality and high functional mold powder products to meet demand of casters.

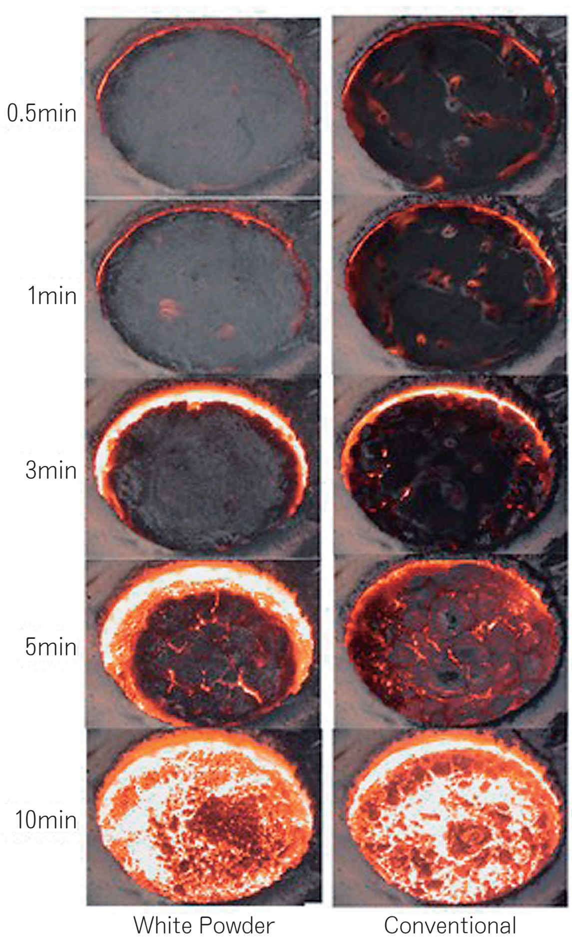

Fig. 9 Comparison of melting property.

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