

Mold Powder Utilizing Glass Powder Recovered from Used Photovoltaic Panels

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Abstract

To contribute to reducing the environmental impact in mold powder production, utilizing waste-derived materials as alternative raw materials is an effective approach. This study focused on recycled raw material produced from photovoltaic glass (PV glass) used in solar panels, hereafter referred to as R-PV glass. The melting behavior and thermal insulation of mold powders formulated by utilizing R-PV glass and adjusting the composition of other raw materials were evaluated. The results showed that the developed mold powder exhibited melting characteristics comparable to those of conventional products, while demonstrating improved thermal insulation. Adding R-PV glass can help recycle waste materials efficiently and may also boost steel quality by providing better thermal insulation due to its exothermic characteristics.

1. Introduction

Mold powder for continuous casting is placed on top of the molten steel in the mold, where it absorbs heat from the steel and then melts. The molten mold powder slag is then consumed by flowing into the gap between the mold wall and the solidified steel shell. In this process, mold powder performs the following functions: 1) Protection of the molten steel surface from oxidation, 2) Thermal insulation of the surface of the molten steel, 3) Absorption of non-metallic inclusions that floats to the surface of the molten steel, 4) Lubrication between the mold and the solidified shell, 5) Heat removal control between the mold and steel shell. In these ways, the mold powder greatly contributes to the operational stability and the improvement of steel quality.

The heat necessary for melting mold powder is supplied directly by the molten steel, and this amount of heat cannot be regulated during the casting process. As a result, the thickness of the molten layer

formed by the mold powder is determined solely by the choice of raw materials and the overall composition of the mold powder. If inappropriate raw materials are selected, this can lead to the formation of a molten layer with insufficient thickness. An inadequately thick molten layer will not provide proper lubrication between the mold and the solidified steel shell. Furthermore, thermal insulation of molten steel surface in the mold is also an important role; if thermal insulation is insufficient, inclusion defects and surface solidification of the molten steel in the mold may occur, leading to deterioration in steel quality, instability in operations, and insufficient productivity. Therefore, meticulous attention should be paid to the adjustment of raw materials in the mold powder.

In recent years, the steel industry has actively promoted carbon neutrality and Sustainable Development Goals, including recycling of used materials and utilization of by-products. In this study, we focused on the reuse of cover glass (photovoltaic glass: PV glass) used on the light-receiving surface of

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solar panels (Fig. 1), which are expected to generate increasing amounts of industrial waste. The PV glass was focused on because it shares a similar composition with mold powder (Table 1). While solar power generation is attracting attention as a renewable energy source, approximately 4,400 tons of used panels are disposed of annually in Japan¹⁾. Solar panels typically have an operational lifespan of approximately 20 to 30 years, and the volume of decommissioned panels is projected to rise significantly in the future.



Fig. 1 Solar panel.

Table 1 PV glass chemical composition

Sample name		PV glass	Mold powder range
Chemical composition / mass%	SiO ₂	72	30-40
	Al ₂ O ₃	2	1-10
	CaO+Na ₂ O	22	25-60
Crystal phase		Amorphous	-



Fig. 2 Photovoltaics panel glass (PV glass) scrap raw material.

To resolve this issue, a mold powder product has been developed utilizing powdered material generated from the crushing of PV glass extracted from decommissioned panels (Fig. 2). In this study, this powdered material is designated as R-PV glass (Recycled PV glass).

2. Features of R-PV Glass

Solar panels are composed of various materials, including cover glass (light-receiving surface), frame, solar cells, terminals, cables, encapsulant, and films. PV glass is used as the cover glass on the light-receiving surface, and after use, it is removed from the panels, separated, and crushed, then either disposed of as industrial waste or partially recycled²⁾. In this development, R-PV glass obtained through was processed to the proper particle size and used as a raw material for mold powder.

To investigate the characteristics of the R-PV glass during the heating stage, which affects melting and thermal insulation before melting, R-PV glass was heated in an electric furnace at 800 °C and then analyzed by XRD to identify mineral component as compared with unheated sample. The result is shown on Fig. 3. The unheated sample was completely amorphous, while crystallization of cristobalite was observed after heating.

The PV glass contains oxides such as CaO and Na₂O, which modify the SiO₂ network structure. As

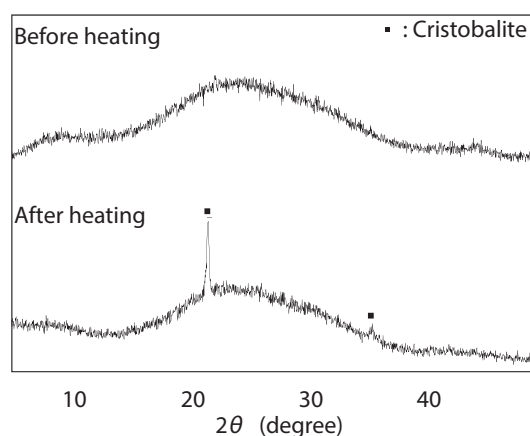


Fig. 3 XRD of PV glass before and after heating to 800 °C.

a result, the chemical composition is regarded as a factor contributing to both the reduction in glass viscosity during heating and a lower glass transition temperature. This facilitates atomic arrangement in glass at lower temperatures, promoting crystallization. The transition in energy level associated with crystallization is anticipated to produce an exothermic effect. Using this exothermic effect in mold powder is expected to improve thermal insulation of the molten steel surface during casting.

3. Development of Mold Powder Using R-PV Glass

3. 1 Example of chemical composition and properties

Table 2 shows examples of mold powder compositions containing R-PV glass. Conventional A represents a standard product typically used for low-carbon steel grade on slab casting (C: 0.02–0.07 mass%). To achieve a composition approximately equivalent to that of Conventional A, developed B was designed with 20 mass% R-PV glass added, and developed C with 30 mass% added. As mentioned before, the chemical composition of mold powder affects the thickness of the molten layer. Therefore, the formulations of the developed products were carefully adjusted in conjunction with the other raw materials. In this study, the products were manufactured and evaluated in fine powder type, however, it can also be provided in granule type through spray granulation process.

3. 2 Characteristic evaluation and discussion

The melting behavior and thermal insulation of mold powder depend on its raw materials, so lab tests were carried out on the samples.

3. 2. 1 Melting property

To investigate the melting property under the conditions close to actual casting, each mold powder sample was added and rapidly heated on molten pig iron surface at 1500 °C in a magnesia-carbon crucible within a high-frequency induction furnace, and its melting characteristics were evaluated. The schematic diagram of the experiment is shown in Fig. 4a, and the results are presented in Fig. 5. No abnormal behavior such as excessive flames, premature decarburization, or the formation of sintered lumps were observed on any sample (Conventional A, Developed B, and C). All samples were fully melted within 360 seconds. From these results, it was confirmed that even with up to 30 % addition of R-PV glass, the melting behavior equivalent to that of the conventional product was achieved, and an appropriate molten layer thickness could be maintained.

3. 2. 2 Thermal insulation property

The thermal insulation property of the mold powder was also evaluated by using a high-frequency induction furnace test. A schematic diagram of the test is shown in Fig. 4b. Mold powder was added and spread over molten pig iron at 1500 °C in a high-frequency induction furnace, and the temperature at a depth of 2 cm from the surface was measured

Table 2 Composition of mold powder and PV glass addition amount

Product name		Conventional A	Developed B	Developed C
PV glass content / mass%		0	20	30
Chemical composition / mass%	SiO ₂	36	37	36
	Al ₂ O ₃	6	6	6
	CaO+Na ₂ O+MgO	43	44	44
	F	8	8	8
	Total carbon	4	4	4
Crystallization temperature / °C		960		
Viscosity / Pa · s		0.38		

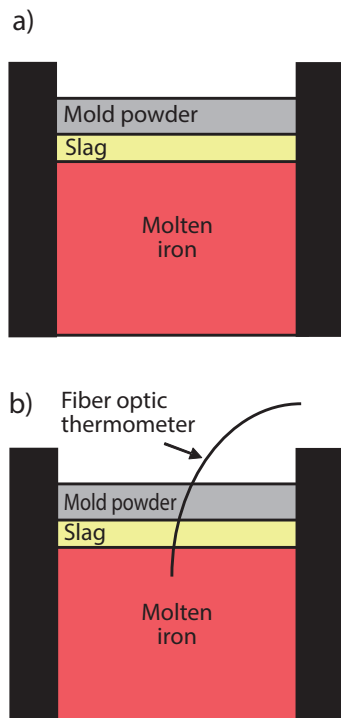


Fig. 4 a) High-frequency test method, b) Optical fiber thermometer test.

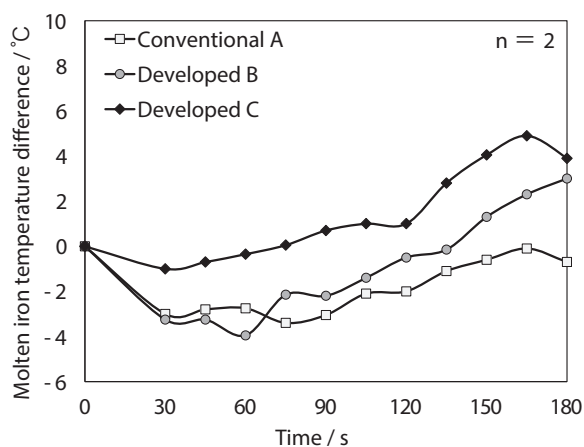


Fig. 6 Molten iron temperature difference at each time interval during mold powder addition of A, B and C.

every 15 seconds for 180 seconds using a fiber-optic radiation thermometer. In addition, the high-frequency power was applied at a constant voltage during the test. The temperature difference between the molten pig iron at the time of mold powder addition and each elapsed time is shown in Fig. 6. As the amount of R-PV glass increased, the molten pig iron temperature increased. This is considered to

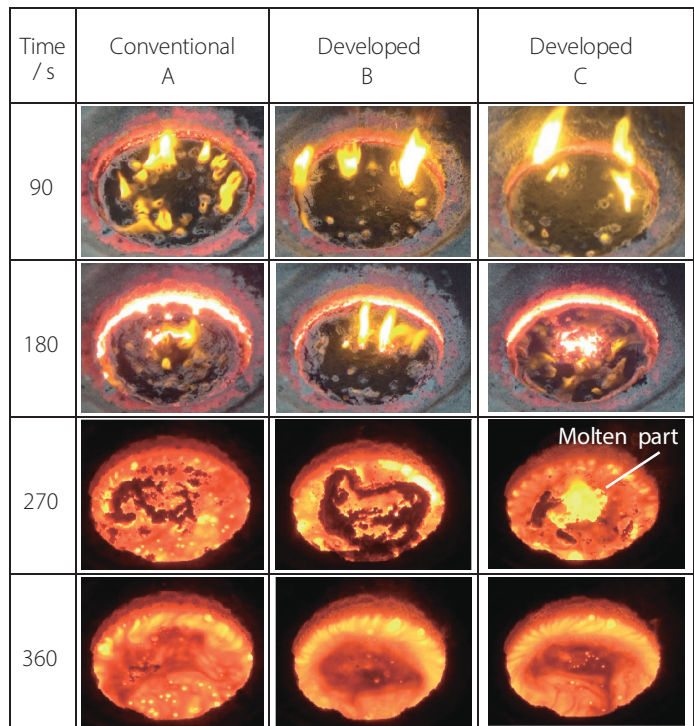


Fig. 5 Melting characteristics of A, B and C.

be due to the exothermic property obtained from energy level transitions caused by crystallization of the R-PV glass, as inferred in Section 2. The results suggest that, in actual casting operations, the addition of R-PV glass to mold powder can improve the thermal insulation of the molten steel surface with its exothermic behavior during heating.

4. Conclusion

An assessment of mold powder that had been meticulously formulated to include R-PV glass, a recycled material derived from used photovoltaic glass has been conducted. The results show it exhibited melting behavior similar to conventional products and demonstrated improved thermal insulation due to its exothermic characteristics associated with crystallization during heating. It was found that the application of R-PV glass in mold powder is feasible. The application of R-PV glass to mold powder not only contributes to reducing environmental impact through the utilization of waste materials but also has the potential to improve productivity by enhancing steel quality through its exothermic property.

References

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