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Development of Energy Saving Type Vertically Grooved Crucible

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1. Although the crucible furnace has various advantages, it has also disadvantage of lower thermal efficiency. However, higher thermal efficiency of the melting crucible itself has yet to be achieved. In this study on the development of a new crucible, the aim was to increase the thermal efficiency of the crucible itself by 5 to 10% compared which conventional melting crucibles by applying vertical grooves around the outer crucible surface which increases the thermal exchange surface area by 30%. We also performed investigations on the physical properties of the developed crucible and microscopic analysis of the melting crucible material in order to clarify the destruction mechanism of the crucible.

Key words: Vertical grooved crucible, Energy saving, Thermal exchange area, Thermal efficiency

2. Introduction

Crucible furnaces are widely used in non-ferrous foundry industry to melt and hold the molten metal. Although crucible furnace has various advantages, it has also disadvantage of lower thermal efficiency. There are various ways to improve its efficiency such as the reuse of combustion exhaust gas heat. However, the thermal efficiency of the melting crucible itself could not be improved so far.

This study describes the melting crucible thermal efficiency improvement of 5 to 10% compared with that of the conventional crucible. This improvement has been made by incresing the thermal exchange surface area of the crucible by 30%.

We also investigated the physical properties of the developed crucible materials and made the microscopic analysis of the melting crucible in order to clarify the destruction mechanism of the melting crucible.

2. Experiment test

2.1 Designing of the melting crucible materials

We have designed well balanced formulation of the crucible compositions with the cosideration of its strength, thermal conductivity, spalling resistance and oxidation resistance. Table 1 shows the crucible composition material formulation and grain distributions.

Table 1. Crucible composition formulation

	SiC	C	Carbon bond	Si	Low melting piont glass	Borides
Material formulation (mass%)	35~50	30~45	10~20	3~8	0~3	0~2
Particle size (μm)	0~250	150~840	liquid	0~325	0~325	0~325

2.2 Crucible manufacturing process

Graphite crucible is manufactured with following production process.

Raw material formulation – Mixing – Kneading – Mixed raw material adjustment – Forming by press – firing – Nondestructive inspection – Impregnation – Baking – Glazing – Coating – Baking – Packing & Shipping.

Raw material formulation is shown in the Table 1.

2.3 Vertically grooved crucible test at the customer

For obtaining the fuel consumption data of the conventional and developed crucibles, those crucibles are actually tested at the customer for 12 months.

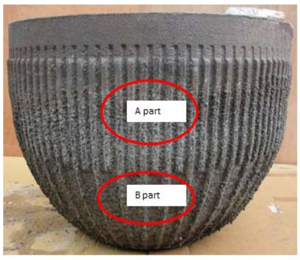

Fig1. Appearance of the crucible after 12 months use

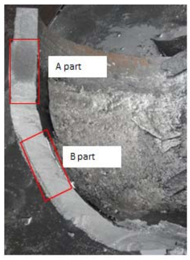

Fig2.Cut crucible photo

After 12 months operation, those crucibles were removed from the furnaces. Then samples were cut out from A part (Oxidized area) and B part (Less oxidized area) as shown in the below Fig. 1 and 2. Then we inspected the samples with optical microscope, SEM and X-ray diffraction. We also analyzed the contents of Si, SiO_2, SiC, B_2O_3 according to JIS-R2015 and JIS-R2011.

3. Result and consideration

3-1 Crucible fuel consumption and life

Thermal exchange surface area of the developed crucible has 30% more than that of the conventional one. As a result of melting test, it has been proved that developed crucible has 5 to 10% less fuel consumption than the conventional crucible. We also made follow-up survey of the life of 30 pcs. each of the developed and conventional crucibles. The result was almost the same as the above result.

3-2 Crucible destruction by composition change

Fig. 3. shows the photos of optical microscope composition of unused crucible and the sample pieces of "A" and "B" parts of the 12 months used crucibles.

Comparing the textures of "A" part (Photo b), "B"part (Photo c) and unused crucible with photo (a), it is distinctive that the amount of flake graphite is significantly reduced.

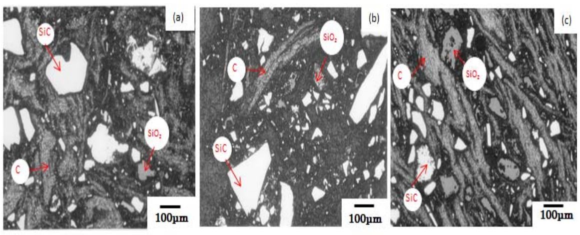

Fig.3.Optical microscope observation of crucible material and the result of phase analysis
(a)Unused (b) "A" part after 12 months usage (c) "B" part after 12 months usage.

Fig. 4 shows the photos of the result of X-ray analysis of the unused crucible, "A" and "B" positions of the sample pieces of 12 months used crucible. Unused crucible (a) and "B" position (c) are lower oxygen content and SiC and little amount of SiO_2 were detected.

On the contrary, higher oxygen content was detected in the severely oxidized "A" position (b), and SiC and the large amount of SiO_2 were also observed.

The large amount of SiO_2 is generated by SiC which starts to be oxidized from 800 degree C, and the chemical reaction of $SiC+2O_2$ to SiO_2+CO_2 forms SiO_2.

In addition to this, metalic silicon in the crucible composition will form beta type ultra fine SiC during firing process which will also form SiO_2 as shown in the above reaction formula. And during firing process, non-reacting metalic silicon will contact with oxigen and directly form SiO_2. So, there are three types of oxidizing reactions.

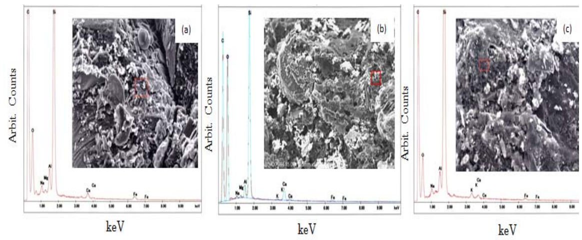

Fig.4. X-ray analysis result of crucible
(a) Before usage (b) "A" position after 12 months usage (c) "B" position after 12 months usage

Those results can also be justified by the result of the components analysis of Si, SiO_2, SiC and B_2O_3. When we compare Si content of un-used crucible component and part A and part B of 12 months used crucible, Si in the part A drastically reduced but SiO_2 content increased in stead.

Those SiO_2 generated as above will create glass film under working temperature which has effect to prevent oxigen to penetrate in the crucible component. This means that main component of flake graphite or SiC can be protected from oxigen. Actual field test result of longer crucible life was the mainly the result of the above effect. At the same time, vertically grooved crucible had the same effect and the same life as the normal crucible. This point was also the benefit of this study.

4. Conclusion

(1) Vertically grooved crucible can achieve thermal efficiency improvement of 5 to 10% by increasing 30% of the thermal exchange surface area.

(2) SiO_2 film generated by metalic silicon is highly effective for preventing oxidation of flake graphite which is the one of the crucible component. However, the film has lack of compactness.

(3) Life of the vertically grooved crucible has almost the same life as the normal crucible.