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Production of Brake Disk by SiC Permanent Mold*

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The permanent mold casting was designed with the SiC mold material which was selected from the stand point of the technical and economical adaptability among many refractory material.

After the casting test of the molds made of such mold material, a mold which contained about 40 % of SiC was found to have qualitatively an excellent adaptability.

The practical casting test which was carried out with this permanent mold for the brake disk could establish the relation between the casting condition and the quality of the brake disk.

As the result, it is concluded that the desirable pre-heating temperature is between 300° C ~ 350° C in case of this mold.

The time interval required for each operation in the casting cycle can be also decided from the cooling time attained for this pre-heating temperature.

1. Introduction

The casting industry in recent years is calling for, more and more, improvement of casting technology with respect to productivity, precision and fettling, and the contribution to its improvement is made mostly by the development of molding technique.

In the current status of casting process, a substantial amount of work is being made by the molding operation, including the preparation and conveyer transportation of sand mix.

Consequently, the modernization of casting plant, apart from the question such as the performance of molding machine or fluid self-hardening sand mold, will come to demand increasing attention to the study on permanent mold casting from the point of view which enables the mass production without use of sands.

In this paper, the authors report the experimental result concerned with a new permanent mold which is formed by the SiC refractory material used for the iron casting of brake disk.

2. The properties of SiC mold for the permanent mold

2.1 The composition of SiC mold and its thermal characteristics

In many recent papers, such permanent mold materials for iron and steel casting are being ex-

amined, about their adaptabilities metallic, carbonaceous and various refractory materials, and the most important property is the thermochemical stability to the metal or slag in liquid states at high temperature.

At present, special refractories, such as carbon, silicon carbide, sinterkorund, zirconia, metallic nitride etc, are thought, in the above respect, more excellent than the metallic or other common refractory mold; and above all, the mold of carbon and silicon carbide material will be particularly practicable from a commercial point of view.

Table 1 shows the chemical composition and the physical properties of the four sorts of such material which were used in this investigation.

The more the SiC content in mold material increases, the more the mechanical strength and the chemical stability increase, but on the other hand, it becomes the more difficult to make such a mold precisely, and the chilling effect of molten metal increases the more.

Now, if the casting condition is the same, the rate of solidification of casting metal is dependent upon $b = \sqrt{\lambda / c \rho}$, which represents the thermal property in the mold (where, λ : the thermal conductivity of mold, c : the specific heat of mold, ρ : apparent density of mold).

From b value shown by Table 1, it is acknowledged that the SiC mold which contains 40 % of SiC cools about 5 times more rapidly, and over 10 times more so, the metallic mold than the green sand mold.

It is necessary to establish the relationship between cooling rate and micrographical structure. At any rate, it is expectable from the result of this

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experiment that the SiC mold combines the merits of both the metallic and the common refractory mold.

2.2 The examination of mold characteristics by test casting

Three sorts of mold which were formed using the materials such as carbon, SiC II and SiC III were qualitatively examined by preliminary test casting and brake block casting.

In the test condition, the chemical composition of cast iron melt was T.C. 3.2 %, Si 1.7 % and Mn 0.6 %, and the pouring temperature was 1320°C ~ 1360°C. The casting test was repeated 20 times in each mold.

Figure 1 shows the cooling curves of test casting of each mold as compared with sand mold casting.

Cooling velocity of test casting increased according to the increase of SiC content in mold material. During 20 times of testing, all test castings resulted in good dimension accuracy and surface condition,

Fig. 1 Cooling curve of test casting

and practically no defects came from mold-metal reaction or mold crack by thermal shock were observed, and it was concluded particularly, that the mold which contains about 40 % of SiC has qualitatively more excellent adaptability than the other two, although this mold material would be better, if it had more ductility.

The metallurgical structure of the product also proved that it could be improved by the more suitable casting conditions such as addition of elements decreasing the chilling effect, higher preheating temperature of the mold and the application of the more adiabatic mold wash.

From above consideration about mold material, authors recommend SiC permanent mold which has SiC content : 55 %, compressive strength : 300 kg/cm², porosity : 20 %, thermal conductivity : 20 kcal/m hr°C, thermal expansion : 0.2 %.

3. The practical casting test of brake disk

The practical casting test of brake disk for rolling stock was carried out with the mold made under above conditions.

In this test, it was expected that the casting could be taken more easily out of the mold, because the shape of disk was rather simple.

The main purpose of this test was, therefore, to establish the relation between casting condition and quality, and the period required of each operation in the casting cycle.

3.1 The composition and shape of SiC mold for brake disk

The material SiC II show in Table 1 was selected as the optimum composition of SiC mold for brake disk.

Figure 2 shows the shape of mold, and the braking surface of disk was set in the drag. Both sides of disk were connected by many ribs, formed

Table 1 Chemical composition and physical property of SiC mold and b value which indicates its thermal property

Material of mold	Chemical composition			Physical property						$b = \sqrt{\lambda c \rho}$	b/b_0 where, b_0 is b to green sand mold
	SiC %	C %	SiO ₂ %	Compressive strength kg/cm ²	Porosity %	Apparent density ρ : g/cm ³	Specific heat C : cal/g°C	Thermal conductivity λ : cal/ cm sec °C	Thermal expansion % (at 600°C)		
Carbon	0	90~92	2~3	450~600	16~18	1.55~1.60	0.2~0.5	0.025	0.15~0.30	0.095	3.5
SiC I	38~40	50~60	7~9	150~170	22~24	1.87~1.90	—	0.046	0.15~0.20	—	—
SiC II	40~42	38~40	14~15	150~200	20~25	1.90~1.92	0.2	0.047	0.13~0.17	0.134	4.9
SiC III	80	—	—	550~650	16	2.5	0.3	0.076	0.395 (at 1050°C)	0.209	7.6
Green sand mold				0.3~0.5	20~30	1.4~1.6	0.25	0.002	—	0.027	1.0
Dry sand mold				15~30	20~30	1.4~1.6	0.22	0.0015	1.5~2.0	0.022	0.8
Metallic mold				—	—	7.1	0.13	0.147	—	0.368	13.4
Agalmatolite brick (SK 30)				550	15~20	2.5~2.6	—	—	1.0	—	—

by six CO₂ sand core, coated with graphite- alcohol system mold wash, set in the cavity of drag.

In order to lift the cope easily after casting, cores (sprue, 50 mm inner dia., riser, 20 mm inner dia.) were inserted respectively in the center sprue and six risers of cope. As shown in Fig. 2, many vents were also prepared to get the better permeability of this mold material.

The weight of the mold was 95 kg for the cope, and 65 kg for the drag.

3.2 Casting test

Table 2 shows the casting condition. The same two SiC molds were distinguished as A and B in each case of two different compositions of molten iron used in this test and a series of three pouring tests taking 60 min ~ 70 min were carried out in

each case.

The wash was double, the inner layer of diatom earth, as adiabatic material, which was suspended in 5 % sodium silicate solution, and the outer layer of acetylene smoke. However, the double coat was provided only on a half of each disk, while a single coat of smoke on the other half.

In the first cycle, pre-heating of the mold was made by pouring 30 kg of melt, which was removed afterwards, but for next cycles, the second and third, the pre-heating was not needed because of the remaining heat of the previous casting.

The chemical composition of pouring metal was T.C. 3.08 % Si. 2.22 % and Sc 0.87 in melt A, and

Fig. 2 SiC permanent mold for brake disk

Table 2 Experimental casting condition

No	Condition of mold				Composition of melt and its mechanical property (by sand casting bar)				Temperature of melt	
	Mold	Mold wash		Pre-heating temperature °C	Composition %	30 mm ϕ $\times$ 500 mm test piece			Melting Temp. (at optical)	Pouring Temp. (at immersion)
		Adiabatic Wash (inner layer)	Acetylen smoke (outer layer)			Hardness H_B	Tensile st. kg/mm ²	FC		
A-1	Mold A	at only half surface	at all surface (every pouring)	Cope 110 Drag 270	T.C. 3.08 G.C. 2.56 C.C. 0.52	195	24	20	1 400	1 310
A-2		as A 1	as A 1	Cope 185 Drag 300	Si 2.22 Mn 0.53 P 0.105 S 0.098 (S _c 0.87)				1 400	1 345
A-3		as A 1	as A 1	Cope 200 Drag 300					1 400	1 348
B-1	Mold B	at only half surface	at all surface (every pouring)	Cope 140 Drag 440	T.C. 3.13 G.C. 2.61 C.C. 0.52	170	18	15	1 395	1 385
B-2		as B 1	B 1	Cope 205 Drag 395	Si 3.09 Mn 0.68 P 0.097 S 0.096 (S _c 0.96)				1 420	1 362
B-3		as B 1	B 1	Cope 190 Drag 390					1 410	1 355

(b), and T_1/T_G and T_1/T_D are the percentages of T_1 to the thickness of upper (C), or lower (D) disk part.

When pre-heating temperature increased from 100°C to 450°C, T_1/T_G or T_1/T_D decreased from 70% to 30%. Concerning the effect of the composition of melt, in the melt (B) with Sc 0.96 it was lower about 5% than in the melt (A) with Sc 0.87.

In Fig. 8, the T_1/T_G % of the upper disk part fluctuates, which is thought to have been caused by the air-gap formation at the mold-metal interface.

Figure 9 shows the Vickers hardness of the disk which was measured from casting surface contacted with SiC mold to that contacted with core.

The lowest hardness, that is H_V 150~160, was indicated in D type graphite plus ferrite structure at SiC side surface, and with progressive transition to inner layer, the hardness increased rapidly because of the increase of pearlite matrix part, and the highest hardness, that is H_V 240~250, was indicated in E type graphite plus dendritic austenite structure, but with the transition to the more inner layer, the hardness decreased again.

Figure 10 shows the relation between pre-heating temperature and hardness at two points in different thickness, namely, the center point of the thickness (a) and the point at 1 mm from SiC side surface (b).

In Fig. 10, the former (a) hardness decreased with the increase of pre-heating temperature, but above 300°C, it became almost constant, while the latter (b) increased from above 200°C, furthermore, the hardness was different with the quality of melts, as the melt B (Sc 0.96) indicated lower hardness (about H_V 35 in the difference) than the melt A (Sc 0.87).

In this case, the effect of mold wash was indistinct, but some further experiments may be necessary to prove the adiabatic effect, as in the metallic mold.

Hereupon, the question whether the inner structure which occupies above 2/3 of the thickness of disk is suitable or not as the material for brake disk must be researched, and it is necessary to get the most favorable quality of melt.

Table 3 shows the present quality of the brake disk produced by sand mold.

In SiC mold, for the reason that the structure has an excessively developed graphite, it is not also desirable to increase the Si % for the purpose of anti-chilling, accordingly, the melt which is between T.C. 3.2% and 3.5%, and Si 2.0% and 2.2% accompanied by inoculation (as Fe-Si) will be necessary to get the same good structure as obtained by sand casting.

From Fig. 8 and 10 (a), the desirable pre-

Fig. 6 Metallurgical structure change from casting surface of SiC side to that of core side

heating temperature is between 300°C and 350°C in case of this mold because T_1 drops more slowly at above 300°C, and further it must be the lowest from

an economical and operational point of view.

3.4 The establishment of casting cycle

The time interval required for each operation in

(a) D type graphite

(b) E type graphite

(c) Fine A type graphite

(d) A type graphite

Fig. 7 Graphite formation change of brake disk

Fig. 8 Relation between T_1/T_c or T_1/T_b and pre-heating temperature

Fig. 9 Hardness change to thickness of disk (at A1 and B1)

Fig. 10 Relation between pre-heating temperature and hardness at center and 1mm from SiC side surface

Table 3 Chemical composition and mechanical property of brake disk used at present time

	Chemical composition					Tensile strength kg/mm ²	Bending deflection mm	Hardness H_v	Heat treatment after casting
	T.C. %	Si %	Mn %	P %	S %				
Brake disk (sand mold casting)	3.3	1.3	0.8	0.115	0.12	28~31	6.0~8.0	207~231	550°C, 1.5 hr annealing

the casting cycle can be decided from the cooling time to pre-heating temperature.

Figure 11 shows the surface temperature change in the mold cavity during cooling time passed after the casting was lifted from mold.

Now, if the time interval attained to 350°C of temperature in the cooling curve is selected as that which is required for the start of next cycle, in case of the drag, it is appropriate to take 15 min-16 min, therefore, the casting must be lifted at 650°C of surface temperature in the mold cavity.

Figure 12 shows the relation between (the difference of the pouring and pre-heating temperature) and (the difference of the surface temperature, at time when the casting was lifted from mold, and pre-heating temperature) with the holding time of brake disk taken into account.

If the surface temperature of drag decreases to 350°C at the end of previous cycle, the temperature increasing at drag surface which must be 650°C in next cycle necessitates 300°C temperature rise.

Figure 13 shows the relation between pouring temperature and holding time which is necessary for 300°C of temperature rise in drag surface.

The solidification time of sprue (50 mm dia.) was 1 min 30 sec on the basis of data, accordingly, if the holding time is 3 min 30 sec the suitable pouring temperature is about 1370°C, and this temperature can be expected to produce good results of casting.

The suitable pouring time is also 30 sec~40 sec

Fig. 11 Relation between surface temperature of cope and drag, and cooling time

on the basis of the data.

The difference of heat capacity between drag and cope in this mold exerted an undesirable effect on the pre-heating temperature of cope, and the depth of T_1 structure at upper disk was always larger than that at lower disk, therefore, for the control of both heat capacities, authors proposed to prepare a cylindrical pocket in the cope.

4. Conclusion

The above is the gist of the study on the production of brake disk by SiC permanent mold.

From the experimental result which was mainly discussed from a view-point of chilling effect on casting, the authors could obtain the reasonable casting condition such as pre-heating and pouring temperature etc., and furthermore, each operation time in the casting cycle was established from the desirable pre-heating temperature.

The authors will expect the application in wider scope of this new mold.

Fig. 12 Relation between (difference of surface and pre-heating temperature) and (difference of pouring and pre-heating temperature)

Fig. 13 Relation between pouring temperature and holding time