China Steel Technical Report, No. 22, pp. 48－52, (2009)

Development of Anti-Splashing Taphole Mud

CHIEN-NAN PAN and CHING-HENG SHAO

New Materials Research and Development Department
China Steel Corporation

Abnormally long-duration splashing constantly occurred during iron tapping at the China Steel Corporation (CSC) No.2 blast furnace after revamping in 2006. This badly affected the stability of the blast furnace operation and reduced the molten iron production. In addition, the campaign life of the main trough and splash cover was shortened drastically. To solve this problem, a specific anti-splashing taphole mud was developed in this study, which especially focussed on: (1) raising the powder/aggregate ratio; (2) adding hardening agent and replacing part of the tar binder with phenolic resin; (3) adding corrosion-resistant aggregates; and (4) adding fine carbon powder. More than 90 tons of the developed taphole mud was produced and field tested. The performance of the taphole mud revealed that the splashing time could be greatly shortened to less than 10 min, while the tapping time could be maintained to 170-180 min and a taphole length of longer than 3.2m achieved.

1. INTRODUCTION

The No.2 blast furnace at the China Steel Corporation (CSC) was revamped and the inner volume enlarge in 2006. Unfortunately, after blowing for less than half year, an abnormally long-duration (>120min.) splashing problem constantly occurred. An excessive splash of the taphole stream not only affects the stability of the blast furnace operation, but also deteriorates the refractory wear of the main trough and splash cover, as shown in Figure 1.

Fig. 1. Abnormal duration splashing during iron tapping at CSC's No.2 blast furnace.

It has been reported that blast gas leaking into the taphole is the most possible root cause for the splashy taphole stream.[1,2] The possible mechanisms for blast gas leakage were viscous fingering, cracks developing in the taphole clay build-up, and bed permeability.[1] Blast gas may also short-circuit into the taphole through cracks or gaps at the blast furnace shell, ramming materials, stave cooler[3,4], mud, carbon brick, and mushroom as schematized in Figure 2. Besides blast gas leakage, there are several variables that also contribute to taphole splashing such as pedestal cracking, taphole blockage and taphole wall roughness[1], taphole point [5] and cast rate.[6]

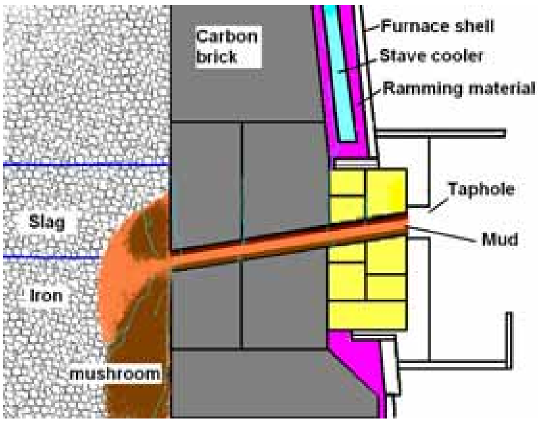

Fig. 2. Types of crack in the schema of taphole area of the blast furnace.

In order to understand the flow characteristics of a splashy taphole stream and its effect on trough refractory wear, Q. He et al. adopted an oil/water model to imitate the molten slag/iron flow in the blast furnace trough.[5] This suggests that the entrainment of bubbles by the impinging taphole stream causes a buoyancy-driven flow pattern within the trough. The identified buoyancy-driven flow causes high velocity and turbulence intensity in the region where the maximum refractory wear occurs.

There have been numerous approaches to solve the splashing problem of the taphole stream, such as adjusting the operation of the blast furnace[2,4], raising the cast rate[2,6], lowering the taphole points[6], and using slurry pressing technology.[3] However, there have been few attempts to minimize a splashy taphole stream with taphole mud. Taphole mud is a material used to plug the taphole of the blast furnace, and is therefore an important monolithic refractory to obtain stable blast furnace tapping operations.

In this article, we develop a specific taphole mud to reduce the splashing problem using the following methods: (1) raising the powder/aggregate ratio to increase the plasticity and crack filling ability; (2) adding hardening agent and replacing part of the tar binder with phenolic resin to improve the hardening rate; (3) adding corrosion-resistant aggregates to improve the slag corrosion-resistance and maintain the tapping time to longer than 150 min.; and (4) adding fine carbon powder to decrease the high-temperature sintering strength for easy drilling. The developed taphole mud was mass produced and field tested in the No. 2 blast furnace of CSC to evaluate the splashing time.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

The formulae of taphole mud are listed in Table 1 along with various factors including binder, hardening agent, powder/aggregate ratio, and corrosion resistance aggregate. Among these formulae, formula A is the original mud used, formula C is the one that uses only resin as binder, and formula D has the largest powder/aggregate ratio.

2.2 Property Tests

2.2.1 Marshall Test

Samples were heated to 50°C for 2 hours and a universal strength testing machine was used to measure their extruding force, as schematized in Figure 3. The samples were measured at a loading rate of 50 mm/min.

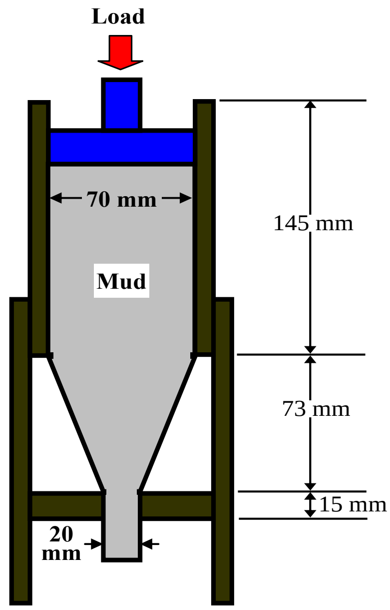

Fig. 3. Schematic diagram for Marshall Test.

2.2.2 Sintering Properties

Samples were heated to different temperatures (400 °C, 600°C, 900°C, and 1500°C) and held for 3 hours in a coke box. Afterwards the sintering properties, including bulk density, apparent porosity, modulus of rupture (MOR) and cold crushing strength, were measured.

2.2.3 Corrosion Test

A rotary slag test furnace was used for the corrosion test. The specimen and rotator cylinder were bolted together with 260 mm ID. The lengths are 320 and 415 mm for the specimen and rotator cylinder, respectively. The furnace was rotated and fired with an oxygen-gas torch. The torch was directed toward the downstream end of the furnace. Six hundred grams of blast furnace slag pellets and six hundred grams of pig iron were charged into the rotary furnace. The furnace was fired to 1,550°C and held for 30min. After 30 min. the torch was shut off and the slag drained as quickly as possible. Then the process was repeated for six cycles. At the end of the test, the furnace was cooled naturally and the specimens were removed from the furnace and cut longitudinally.

Table 1 The characters of different formula taphole mud

Formula	A	B	C	D
Binder	Tar+Resin	Tar+Resin	Resin	Tar+Resin
Hardening agent	×	○	○	×
R	R=1.08	R=1.08	R=1.04	R=1.33
Corrosion resistance aggregate	×	×	○	○

*Note: R = Powder/aggregate Ratio

2.2.4 Hot Crushing Strength

Mud samples were pressed to form a cylinder of 50mm in diameter and 50mm in height, then heated up to different temperatures (i.e. 100°C, 150°C, 200°C, and 250°C) and each held for 30 minutes. After holding for 30 minutes, the mud samples were taken out from the furnace and Hot Crushing Strength Testing was immediately carried out.

3. RESULTS AND DISCUSSION

3.1 Marshall Test

In general, the plasticity of mud is tested by the Marshall Test. The higher the plasticity, the lower the extruding forces. To suppress the taphole splash by filling cracks and gaps, it is better to use a mud with higher plasticity, i.e. lower extruding force.

The extruding force versus the ratio of powder/aggregate is shown in Figure 4. The result showed that the extruding force decreases with higher powder/aggregate ratio in formulae A and D with similar hardening rates and binders. This indicated that fine powder can increase the mud plasticity. In addition, we can find that the extruding force is lower by adding resin in formula C compare to formulae A and B with similar powder/aggregate ratios. It is evident that the powder/aggregate ratio and the binder of mud can affect the extruding force.

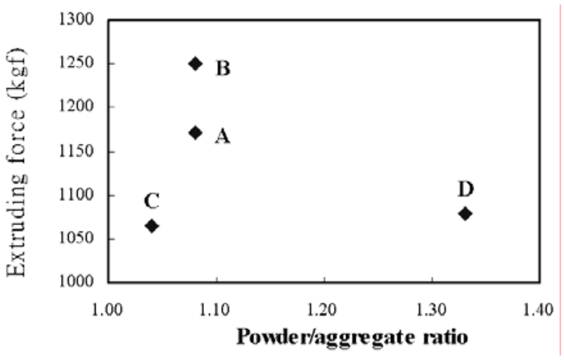

Fig. 4. Relationship between extruding force and powder/aggregate ratio.

3.1.1 Sintering Properties

In this investigation, we diminished the mud sintering strength to raise the taphole-opening workability. It has been reported that the taphole-opening workability is affected by the mud property.(7,8) A good quality mud should be easy to drill during taphole-opening. From the observation of previous field operations, easy-opening mud should have a lower cold crushing strength. Normally, the cold crushing strength of taphole mud at 1,500°C is taken as the index to check the taphole-opening workability.

Table 2 shows the sintering physical properties of taphole mud, including bulk density, apparent porosity, modulus of rupture (MOR) and cold crushing strength after firing at 1,500°C. As shown in Table 2, the order of cold crushing strength at 1,500 °C is: B > C > A > D. Among these muds, formula D is the easiest mud to drill through due to its having the lowest cold crushing strength.

Table 2 Sintering physical properties of mud after firing at 1,500 °C

	A	B	C	D
BD (g/cm^3)	2.15	1.92	2.08	2.0
AP (%)	27.51	30.92	24.41	23.94
CCS (MPa)	14.6	22	19.1	10.6
MOR (MPa)	5.2	3	6.1	4.5

*Note: BD=bulk density, AP= apparent porosity,
CCS= cold crushing strength,
MOR= modulus of rupture

For other physical properties, the order of modulus of rupture is: C > A > D > B, the order of apparent porosity is: B > A > C > D, and the order of bulk density is: A > C > D > B. These properties may affect the ability of corrosion resistance.

3.1.2 Corrosion Test

Essentially, the slag corrosion resistance is related to the apparent porosity, the modulus of rupture, and the anti-corrosion component. Here, we evaluate the slag corrosion resistance by using rotary slag test. The result of slag corrosion test is shown in Figure 5. Lower corrosion index represents a better slag corrosion resistance. Therefore, formulae B, C and D have better slag corrosion resistance than formula A. Among these muds, formula C has the best slag corrosion resistance, this result is closely related to its having the highest modulus of rupture, a lower apparent porosity and an added anti-corrosion component compared to the other formulations.

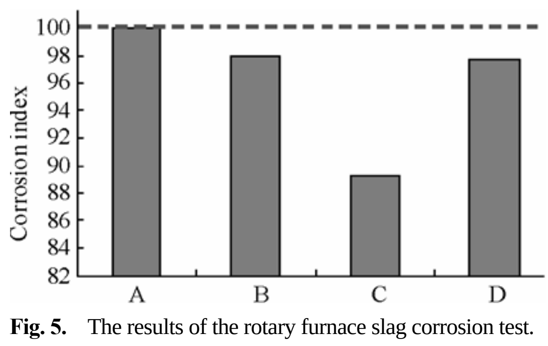

Fig. 5. The results of the rotary furnace slag corrosion test.

3.1.3 Hot Crushing Strength

In order to suppress the blast furnace gas leakage, the blast gas pressure must be taken into consideration. If we want to effectively suppress the gas leakage with mud, the strength of mud must larger than the blast gas pressure. High thermal strength of mud is beneficial to reduce the crack formation and suppress the splashy stream. Form the experimental observation, we found that the mud started to solidify and form strength at about 200~250 °C. Therefore, the Hot Crushing Strength at 200°C, and 250°C would be an good index to evaluate the ability of suppressing the gas leakage.

The result of Hot Crushing Strength at different temperatures (i.e. 100°C, 150°C, 200°C, and 250°C), is listed in Figure 6. Formula A begins to lose its plasticity at 200°C and the Hot Crushing Strength is about 0.7 kg/cm^2 and 2.1 kg/cm^2 at 200°C and 250 °C, respectively. Formula B begins to lose its plasticity at 150~200°C, and the Hot Crushing Strength is about 0.5 kg/cm^2 and 4.3 kg/cm^2 at 200°C and 250 °C, respectively. Formula C begins to lose its plasticity at 130~200°C, and the Hot Crushing Strength is about 19.5 kg/cm^2 and 35.2 kg/cm^2 at 200°C and 250 °C, respectively. Formula D begins to lose its plasticity and solidify at around 200°C, the Hot Crushing Strength is about 0.7 kg/cm^2 and 2.6 kg/cm^2 at 200°C and 250 °C, respectively.

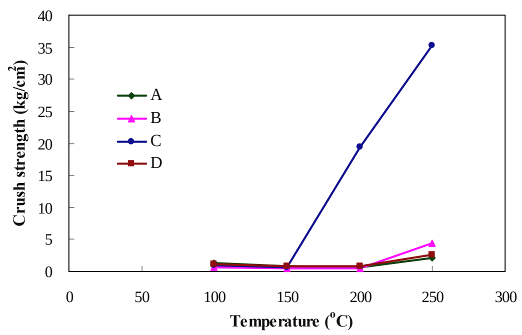

Fig. 6. Relationship between Hot Crushing Strength and Temperature.

Among these formulae, formula C has the largest Hot Crush Strength at 200°C and 250 °C, and it can have more benefit to suppress the gas leakage. The major difference between formula C and the other formulae is that formula C only uses Resin as the binder. Therefore, the effect of Hot Crushing Strength at 200°C and 250 °C will be more remarkable by using resin as the binder.

3.1.4 Field Test

The developed taphole muds were mass produced and field tested in the CSC No. 2 blast furnace and the results are listed in Table 3. The results show that the hardening rate was increased by adding the hardening agent from formula A to formula B, and was further enhanced by using only resin binder in formula C. The hardening rates for formulae A, B, and C at 250°C is 0.14, 1.51, and 6.96 MPa/hr, respectively. The higher the hardening rate, the shorter the splashing time that can be observed with the similar powder/aggregate ratios in formulae A, B and C, as shown in Figure 7. The splashing time is about 120 min. for formula A, and about 50 min. for formula B, but only about 35 min. for formula C. Obviously, the higher hardening rate does reduce the taphole splashing time.

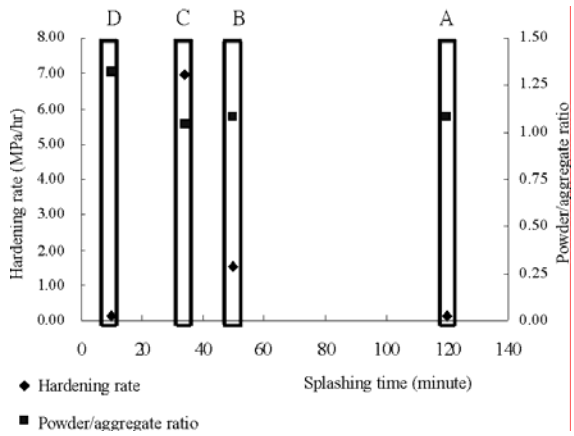

Fig. 7. Effect of hardening rate and powder/aggregate ratio for splashing time.

Table 3 Mud performance results of field testing in CSC's No.2 BF

Formula	A	B	C	D
Contant	T+Re, H(X) R=1.08	T+Re,H(O) R=1.08	Re, H(O) R=1.04 CR	T+Re, H(X) R=1.33 CR
Hardening Rate (MPa/hr)	0.14	1.51	6.96	0.65
Tapping time (min)	~160	~150	~150	~180
Tapping length (m)	~3.1	~3.1	~3.1	≧3.2
Splashing time (min)	~120	50	34	≦10

*Note: T=Tar, Re=Resin, R = Powder/aggregate Ratio, H=hardening agent,
CR= corrosion resistance carbon aggregate

From the field test results, we found that increasing the powder/aggregate ratio can drastically reduce the splashing time by using formula D. It is evident that a higher powder/aggregate ratio has more fine particles to fully fill the gaps and cracks, and that the blast gas short-cutting to the taphole can be stopped.

Among these muds, formula D has the best performance due to the iron tapping splashing time being drastically shortened from 120min. down to less than 10min. Meanwhile, a tapping time of ~180min. and the taphole length of more than 3.2m, with ease of drilling, can be achieved.

4. CONCLUSIONS

(1) A specific taphole mud for anti-splashing was developed and field tested. The field performance of the mud revealed that the splashing time was greatly shortened to less than 10 min, while a tapping time of 170-180 min, and a taphole length of longer than 3.2m could be achieved.

(2) The powder/aggregate ratio of taphole mud is the most effective factor for reducing the splashing time.

(3) The extruding force decreases with increasing powder/aggregate ratio and/or adding resin in the binder.

(4) The Hot Crushing Strength at 200^{o}C and 250^{o}C can be increased by adding resin in the binder, and the higher strength is beneficial to suppressing the gas leakage.

REFERENCES

1. Paul Zulli and Daniel Maldonado: Flow behaviour of blast furnace splashy taphole stream. 2006 BSL-CSC research meeting.
2. Qinglin He, Paul Zulli, Francis Tanzil, Bob Lee, Jeff Dunning and Geoff Evans: Flow characteristics of a blast furnace taphole stream and its effects on trough refractory wear. ISIJ Int., 2002, vol. 42, No 3, pp. 235–242.
3. Wang Zhi, Yu Chengzhong and Li Yuping: Application of slurry pressing technology in solving large BF iron notch splash, Angang Technology, 2007, vol. 5, pp. 41-43.
4. Shu Wenhu, Kong Xiao-xin and Chen Shengxiang: Improvement in technology of tapping hole maintenance of No. 6 BF in WISCO, Wisco Technology, 2006, vol. 44, pp. 1-7.
5. Qinglin He, Geoff Evans, Paul Zulli, Francis Tanzil and Bob Lee: Flow characteristics in a blast furnace trough, ISIJ Int., 2002, vol. 42, No 8, pp. 844–851.
6. P. Stevenson and Q. He.: Slug flow in a blast furnace taphole, Chemical Engineering and Processing, 2005, vol. 44, pp. 1094-1097.
7. Takashi Matsunaga, Minoru Kataoka and Ichiro Takita, Densification of taphole mix for blast furnace, Journal of the Technical Association of Refractories, Japan, 2002, vol. 22, No.3, pp. 276.
8. Nobuaki Muroi, New taphole mud for blast furnace, Taikabutsu Overseas, 1997, vol. 19, No.3, pp. 24-27.

□