Development of Completely Backward Inclined Lining for BOF

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Abstract

We would like to present a "Completely Backward Inclined Lining" which is an optimum lining for BOFs. There are 36 possible lining combinations for the combined lower knuckle, barrel and cone sections. By making full use of the latest structural analysis technology (FEM), all cases were studied. As a result, we can expect that brick fractures and gaps between bricks which cause drop off will not occur, if backward inclined or round-corner linings are applied for the lower knuckle section and backward inclined linings are applied for the barrel and cone sections.

1. Introduction

There have been many studies on BOF linings which are installed from bottom to mouth layer by layer in a rising direction. Those studies deal with the problem of preventing bricks from dropping off due to cracking and removal of chilled steel which has penetrated into large gaps between the bricks[1)-3)]. Especially, the linings at the cone and lower knuckle sections where damage is greatest have been often investigated. In such studies, it is important to comprehend how large stress is generated in linings and how bricks move. For that purpose, structural analysis technology including the FEM (Finite Element Method) is useful[4)].

Our recent studies based on structural analysis technology clarifies that relatively high stress is generated even at the barrel as well as at the above mentioned sections[2)]. However, the barrel lining has been little studied. Furthermore, the most suitable installation for combination linings for the knuckle, barrel and cone sections which are installed in a rising direction has not been studied. That is to say, an optimum BOF lining has not been proposed yet.

We investigated in detail about various lining layer combinations in order to attain an optimum BOF lining.

The backward inclined lining for the BOF cone which we have presented previously will be an useful model for our studies[3),5)]. It is an optimum design for reducing stress and gaps between the bricks. The results obtained when the backward inclined lining is applied to all sections must be studied and compared to other linings. In principle, there are three inclination possibilities: horizontal, forward inclined and backward inclined (abbreviated as H, F and B at top of diagrams). The lining is applied to the lower knuckle, barrel and cone sections including mouth section in the cone (abbreviated as K, B and C at top of diagrams). However, the lower knuckle section has 4 possibilities, as there is also a round-corner lining. So, there are a total of 36 lining combination possibilities which must be investigated. This paper cannot present the results of all lining possibilities for lack of space. Representative cases which have been picked up describe how the results change with lining combinations. And finally an optimum vertically installed BOF lining is presented.

2. Proposal of Completely Backward Inclined Lining

Our studies indicated that the backward inclined lining at the cone did not generate any stress or produce gaps between the bricks[3),5)]. FEM analysis was performed for a backward inclined lining combination which was installed at the lower knuckle, barrel and cone sections, as shown in Fig. 1.

As expected according to FEM analysis results, no high stress and no gaps between the bricks are produced.

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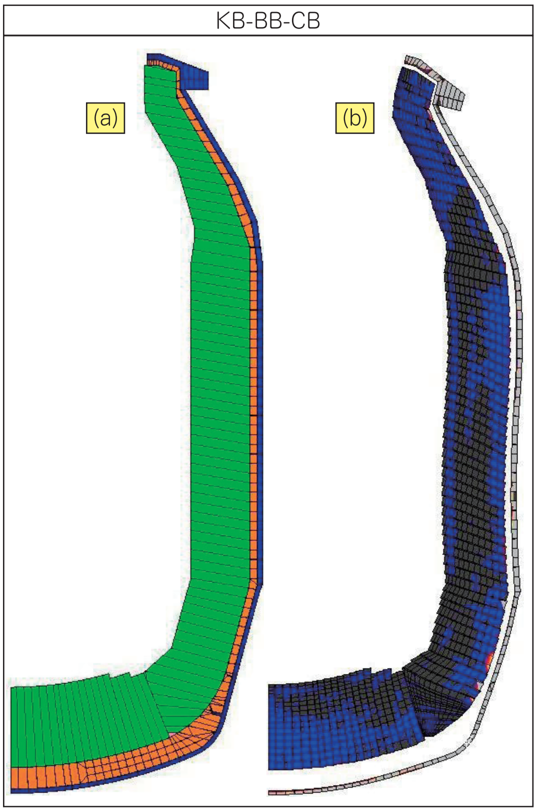

Fig. 1 Rising direction installed completely backward inclined lining model shown in (a). Stress distribution and intensified deformaton shown in (b). Refer to table 1 for meaning of KB-BB-CB symbols.
----- Safety lining is eliminated for easy viewing, as shown in (b).

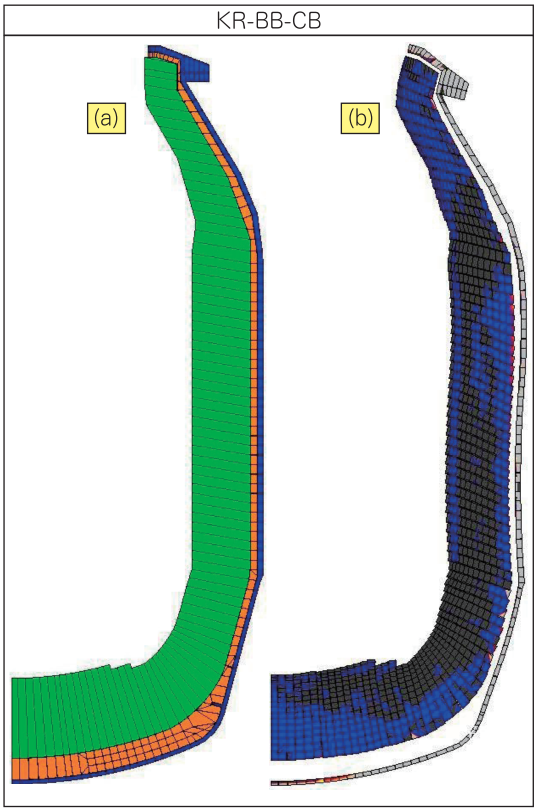

Fig. 2 Completely backward inclined lining at the barrel and cone and round-couner lining at the lower knuckle shown in (a). Stress distribution and intensified deformaton shown in (b).

Fig. 1 shows the stress distribution with intensified deformation just before tapping. In addition, the results obtained for the complete operating cycle are very similar to those just before tapping.

Then we checked the round-corner lining of which installation is similar to the backward inclined lining at the lower knuckle section, as shown in Fig. 2. Fig. 2 shows the same results as Fig. 1. Thus, we were able to predict that the completely backward inclined lining would be optimum for BOFs.

3. Features of Conventional Horizontal Lining

The optimum backward inclined lining is shown in Figs. 1 and 2. We compared it to a conventional horizontal lining to confirm its superiority.

The conventional horizontal lining was applied for all the sections of the lower knuckle, barrel and cone[2]. A model of the horizontal lining and results of the analysis are shown in Fig. 3.

The common results for the lower knuckle, barrel and cone sections are as follows. Higher stress in the conventional horizontal lining than those in the completely backward inclined lining was generated at all sections, oscillated with each operating cycle and peaked just before and after tapping when the temperature in the furnace was highest. The features of each section are described as follows.

High stress was generated at the middle part of the

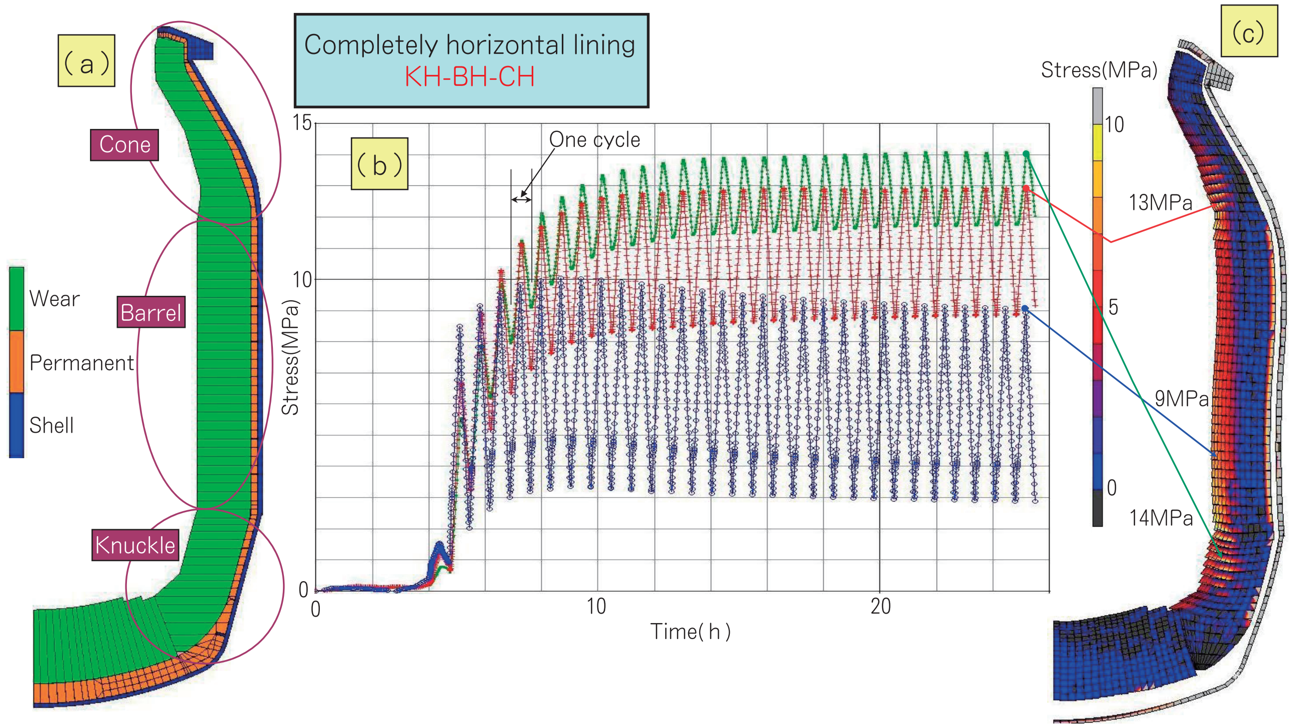

Fig. 3 Completely horizontal lining model (a) , increase of stresses with time (b). Stress distribution and intensified deformation just before steel tapping at 30ch (c).

lower knuckle section, which increased with each operating cycle, and attained a constant level after about 10 cycles. The deformation diagram which exaggerates brick displacement indicates that bricks at this section were warped with the middle bowing down, causing high stress.

The stress at the barrel section was highest after several cycles from the starting of operation and attained a constant but slightly lower level after that time. Stress gradually decreases with height in the barrel. However, the possibility of crack generation in bricks which were installed from the lowest step to the middle of the barrel section was high because the stress even at the middle part was too high.

The stress at the lower part of the cone section near the barrel was even higher, and increased with each operating cycle, attaining a constant level after about 10 cycles. Bricks at this section were warped with the middle bowing up, causing high stress.

It was presumed that bricks would be damaged by cracking at the middle part of the lower knuckle section, at the part of a lowest step to the middle of the barrel section and at the lower part of the cone section.

4. Backward Inclined Linings Combined with Horizontal Linings

We confirmed that the horizontal linings were poor. The backward inclined and horizontal linings were applied for each section of the lower knuckle, barrel and cone in order to study whether the horizontal lining would have a bad affect on the backward inclined lining or not. The results are shown in Fig. 4.

There were no cases of higher stress in the sections installed with a backward inclined lining, but stress was high in the horizontal lining sections. This means that the type of lining in one section does not affect other sections.

5. Backward Inclined Linings Combined with Forward Inclined Linings

We confirmed the horizontal lining to be poor wherever it was installed and however it was combined with other

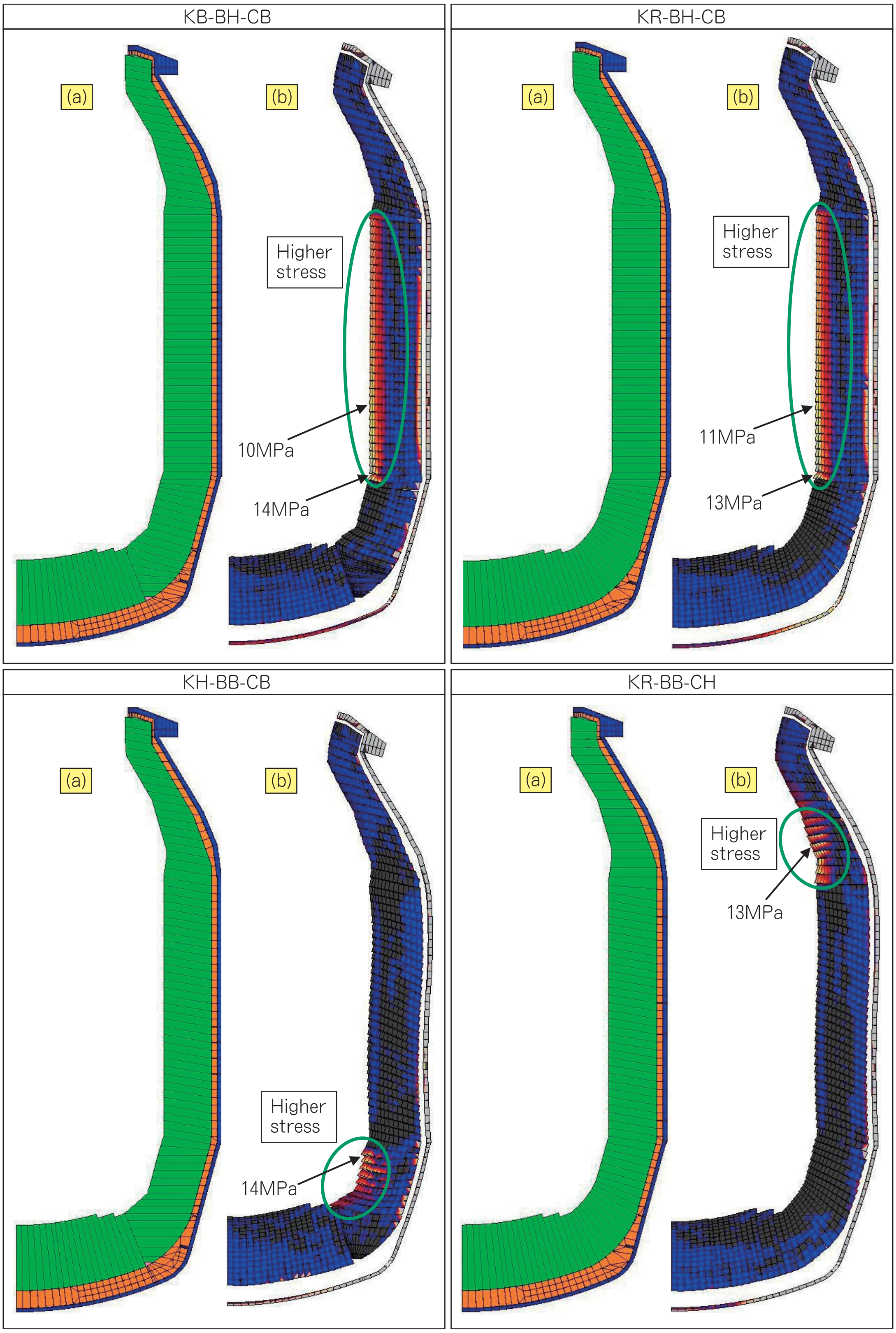

Fig. 4 BOF lining models in which the horizontal and backward inclined linings are applied to various lower knuckle, barrel and cone combinations shown in (a). Stress distribution and intensified deformaton shown in (b).

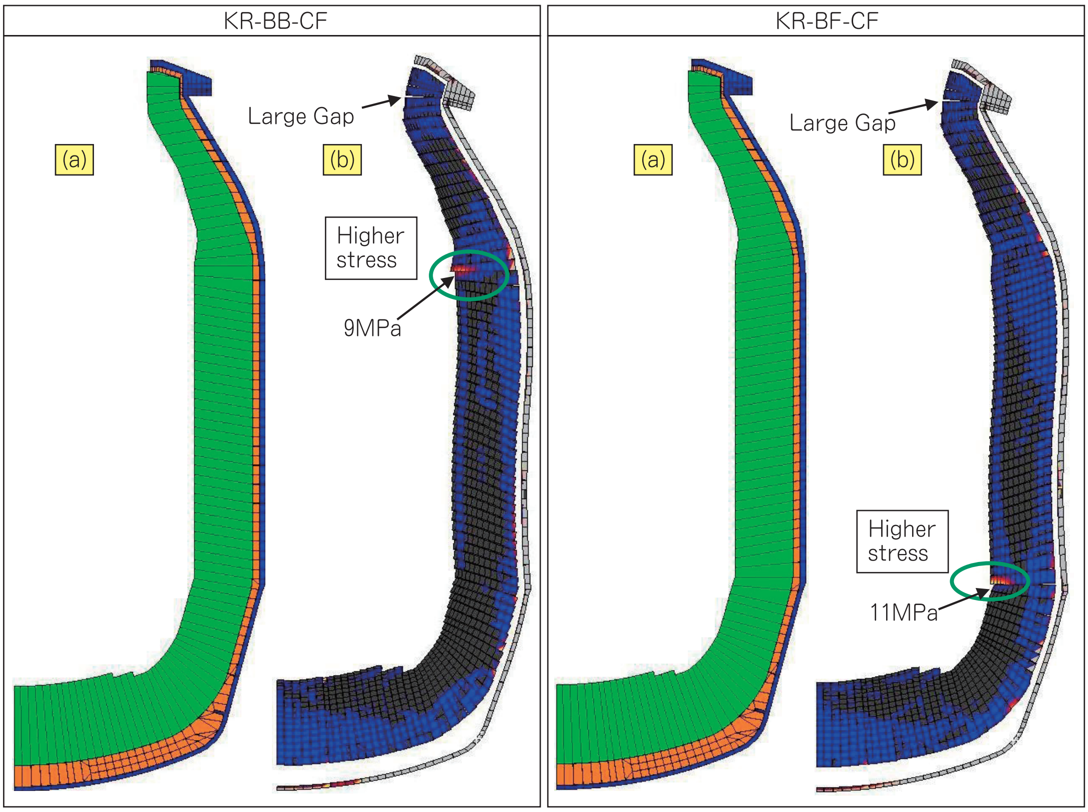

Fig. 5 Lining models of cone: forward inclined, barrel: backward inclined, lower knuckle: round-corner and cone: forward inclined, barrel: forward inclined, lower knuckle: round-corner, as shown in (a). Stress distribution and intensified deformaton shown in (b).

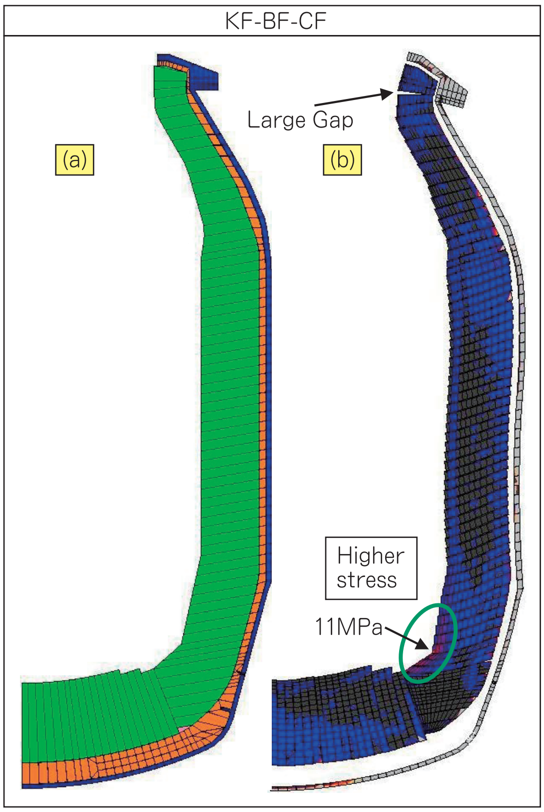

Fig. 6 Completely forward inclined lower knuckle, barrel and cone lining model shown in (a). Stress distribution and intensified deformaton shown in (b).

linings. The remaining lining combination which was investigated was the forward inclined - backward inclined lining combinations. The results are shown in Fig. 5.

Stress was higher at the boundary between the backward inclined and forward inclined lining sections. In addition, when the forward inclined lining was applied for the cone section, it produced large gaps between the bricks at the mouth at the upper part of the cone. Gaps are bad because metal can penetrate into such large openings and bricks easily drop off during removal of the chilled steel.

6. Completely Forward Inclined Linings

So, we were also able to confirm that a combination of different linings is not advantageous. Finally, we checked the case of forward inclined linings being applied to all sections. The results are shown in Fig. 6.

Gaps between bricks, a common fault of forward inclined linings, were similarly generated in this case. This is the same as the results in Fig. 4. In addition, high stress was

Table 1 Lining types and combinations applied for lower knuckle, barrel and cone sections and results decided by the structural analysis

Symbol for lower knuckle section	Symbol for barrel section	Symbol for cone section	Symbol represents combination of lining types for three sections	Linings including the horizontal linings	combination of different linings	Same lining used for three sections	Reference
KH	BH	CH	KH-BH-CH	NG (No good)			Fig.3
		CF	KH-BH-CF	NG			
		CB	KH-BH-CB	NG			
	BF	CH	KH-BF-CH	NG			
		CF	KH-BF-CF	NG			
		CB	KH-BF-CB	NG			
	BB	CH	KH-BB-CH	NG			
		CF	KH-BB-CF	NG			
		CB	KH-BB-CB	NG			Fig.4
KF	BH	CH	KF-BH-CH	NG			
		CF	KF-BH-CF	NG			
		CB	KF-BH-CB	NG			
	BF	CH	KF-BF-CH	NG			
		CF	KF-BF-CF			NG	Fig.6
		CB	KF-BF-CB		NG		
	BB	CH	KF-BB-CH	NG			
		CF	KF-BB-CF		NG		
		CB	KF-BB-CB		NG		
KB	BH	CH	KB-BH-CH	NG			
		CF	KB-BH-CF	NG			
		CB	KB-BH-CB	NG			Fig.4
	BF	CH	KB-BF-CH	NG			
		CF	KB-BF-CF		NG		
		CB	KB-BF-CB		NG		
	BB	CH	KB-BB-CH	NG			
		CF	KB-BB-CF		NG		
		CB	KB-BB-CB			Good	Fig.1
KR	BH	CH	KR-BH-CH	NG			
		CF	KR-BH-CF	NG			
		CB	KR-BH-CB	NG			Fig.4
	BF	CH	KR-BF-CH	NG			
		CF	KR-BF-CF		NG		Fig.5
		CB	KR-BF-CB		NG		
	BB	CH	KR-BB-CH	NG			Fig.4
		CF	KR-BB-CF		NG		Fig.5
		CB	KR-BB-CB			Good	Fig.2

Symbols represented as follows.

Lining \ Section	Lower Knuckle	Barrel	Cone
Holizontal	KH	BH	CH
Forward Inclined Lining	KF	BF	CF
Backward Inclined Lining	KB	BB	CB
Round Corner Lining	KR	—	—

generated at the lower part of the lower knuckle section. These results are poor.

7. Conclusion

36 possible lining combinations including the results mention above are shown in Table 1.

The completely backward inclined lining was confirmed to be the only optimum BOF lining after investigating all lining types and combination possibilities.

References

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