

転炉逆傾斜フルライニング構造の開発

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. はじめに

転炉の高さ方向のウェアーライニングについては、れんがの割れ損傷またはれんが間に侵入した地金除去の影響によるれんがの脱落抑制を図って、過去に多くの検討が行われている^{1)・3)}。特に、損傷の大きい絞り部、下部ナックル部のライニングの検討が多い。これらの検討では、ライニングに生じる応力やウェアーれんがの移動状況を知ることが重要であり、その目的には有限要素法(FEM)を用いた構造解析の方法が役に立つ⁴⁾。

構造解析を用いた著者らの最近の検討では、前述の部位だけでなく、直胴部にも比較的大きな応力が生じることがわかった²⁾。ところが、直胴部のライニング検討はほとんど行われたことがない。また、下部ナックル部、直胴部、絞り部の高さ方向ライニングを組み合わせ、全体として最適な

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 useful⁴⁾.

Our recent studies based on structural analysis technology clarifies that relatively high stress

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積み方を検討した事例もないようだ。すなわち、理想的な転炉ライニングとはどのようなものなのか提案されたことがない。

そこで、著者らは、この理想的な転炉ライニングを得るために、高さ方向のライニング組み合わせについて詳細に検討した。

ここで参考になるのが、著者らが提案している絞り部逆傾斜積み構造である^{3),5)}。この積み方は応力を発生させず、れんが間に隙間も生じさせない最適な積み方である。この逆傾斜積みを全ての部位に適用したらどのような結果が得られるだろうか、また、それと他の積み方と比較したらどうなるかを調べることにした。原則として、高さ方向の積み方には、水平積み、傾斜積み、逆傾斜積みの3つのパターンが選択できる(図中に、それぞれH,F,Bの略号で表す)。それぞれが、下部ナックル部、直胴部、絞り部(ここでは、炉口部も含めて絞り部と考える)の3つの部位に適用できる(図中に、それぞれK,B,Cの略号で表す)。ただし、下部ナックル部にはラウンドコーナー積みを追加した4パターンがある。結局、検討対象のライニング組合せ数は36ケースである。本報告では、紙面の都合により36ケース全ての結果を示すことができないので、代表的なケースを取り上げ、ライニングの組合せを変えたときの特徴を示し、転炉高さ方向に関する理想的なライニングを提案する。

2. 逆傾斜フルライニング構造の提案

我々の研究では^{3),5)}、絞り部を逆傾斜積みにした場合は、応力の発生もなく、れんが間に隙間の生じることもないことがわかっている。そこで、下部ナックル部、直胴部、絞り部の全てを逆傾斜積みにした場合のFEM解析を行った。結果をFig. 1に

is generated even at the barrel as well as at the above mentioned sections²⁾. 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.

示す。

予想したように、応力の発生もなく、れんが間に隙間も生じていない。Fig. 1 は、出鋼直前の応力分布と強調した変形図であるが、結果は、いつの時点でも同じであった。

さらに、積み方が逆傾斜積み に似ているラウンドコーナー積みを下部ナックル部に適用してみた (Fig. 2)。結果は、Fig. 1 と同様であった。

以上のように、逆傾斜フルライニング構造は、転炉ライニングにとって理想的であることがわかった。

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. Fig. 1 shows the stress

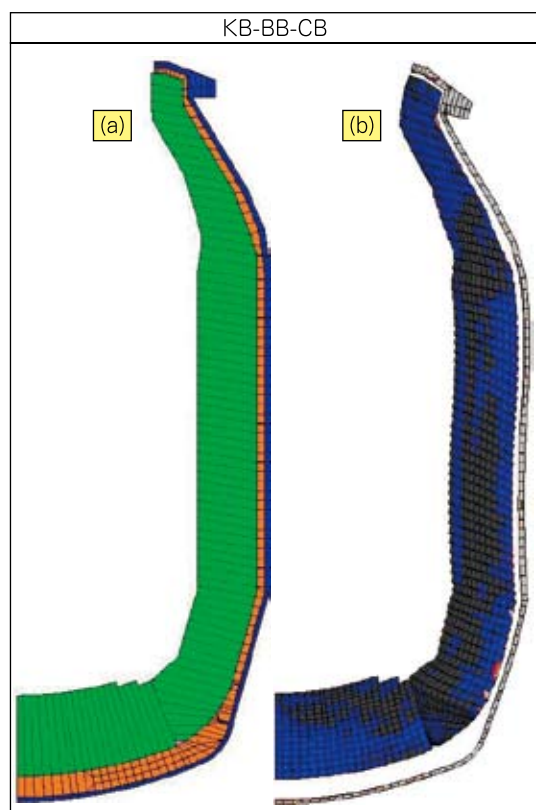


Fig. 1 Rising direction installed completely backward inclined lining model shown in (a). Stress distribution and intensified deformation shown in (b). Refer to table 1 for meaning of KB-BB-CB symbols. ----- Safety lining is eliminated for easy viewing, as shown in (b).

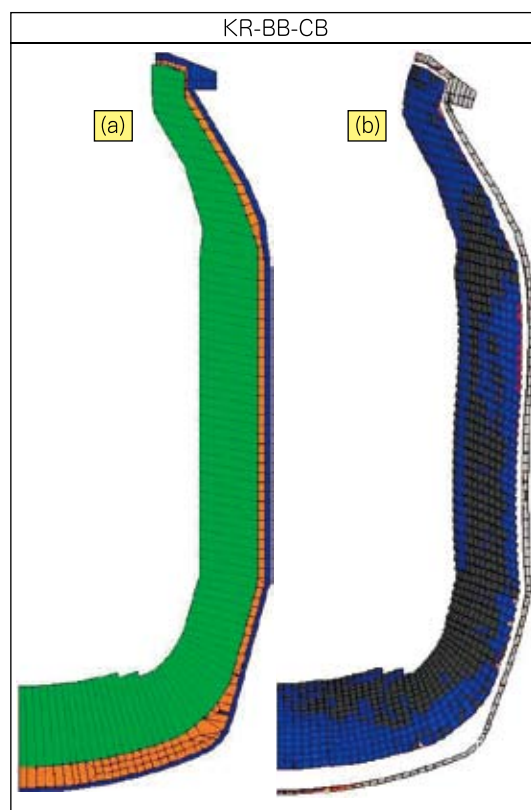


Fig. 2 Completely backward inclined lining at the barrel and cone and round-corner lining at the lower knuckle shown in (a). Stress distribution and intensified deformation shown in (b).

3. 従来の水平積みライニングの特徴

Figs. 1–2 は理想的なライニングであるが、それでは、従来のライニングはどのような特徴を持ち、どのように悪かったのか、それを確認することにした。

従来、一般的に採用されていた水平積みライニングを下部ナックル部、直胴部、絞り部の全ての部分に適用した²⁾。Fig. 3 に水平積みライニングのモデルと解析結果を示す。

下部ナックル部、直胴部、絞り部に共通していることは、それぞれの部位に比較的大きな応力が生じていること、その応力が稼働のサイクルにつれ振動していること、また、各サイクルでピーク応力が生じる時期がいずれもほぼ同じ出鋼前後の炉内温度が高くなったときである。以下に、各部

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

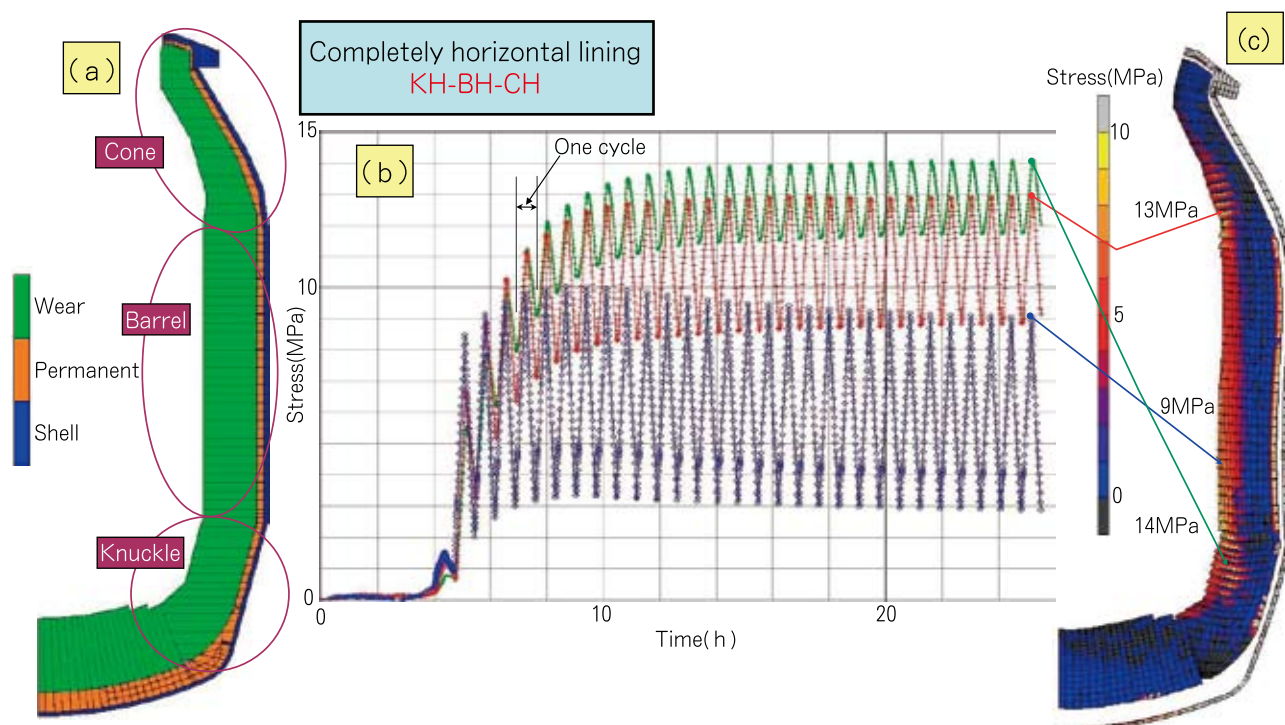


Fig. 3 Completely horizontal lining model (a) , increase of stresses with time (b). Stress distribution and intensified deformation just before steel tapping at 30ch (c).

位の特徴を示す。

下部ナックル部では、その中央部に特に大きな応力が生じ、稼働とともに増大しているが、10サイクルを超えた付近からほぼ一定になっている。また、れんがの移動量を強調した変形図からわかるように、下部ナックル部のれんがは下に凸の変形を受け、これが大きな応力の原因になっている。

直胴部では、最も大きな応力は稼働開始から数サイクル目に生じ、以降はやや低位安定した応力状態を示している。また、ここでは下方ほど発生応力が大きく、上方に向かって徐々に低下する特徴を示している。しかし、直胴部の中段でも十分に高い応力が発生しているので、直胴部の下段から上方に向かってれんがに亀裂が生じる危険性が高い。

絞り部では、直胴部に近いその付け根に大きな応力が生じ、稼働サイクルごとに振動しながら増大し、10サイクルを超えた付近からほぼ一定になっている。また、絞り部のれんがは上に凸の変形を受け、これが大きな応力の原因になっている。

以上より、れんがに割れ損傷が生じる箇所は、下部ナックル部では、その中央部付近、直胴部ではその下段から中段にかけての箇所、絞り部ではその付け根の箇所が特に危険であることがわかった。

4. 水平積みと組み合わせたときの逆傾斜積み

水平積みライニングは良くないことがわかった。そこで、下部ナックル部、直胴部、絞り部のそれぞれに逆傾斜積みと水平積みを組合せ適用したときに、水平積みが逆傾斜積みに悪影響を及ぼすか否かを検討した。結果をFig. 4に示す。

いずれも逆傾斜積み部分には大きな応力の発生

superiority.

The conventional horizontal lining was applied for all the sections of the lower knuckle, barrel and cone²⁾. 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 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

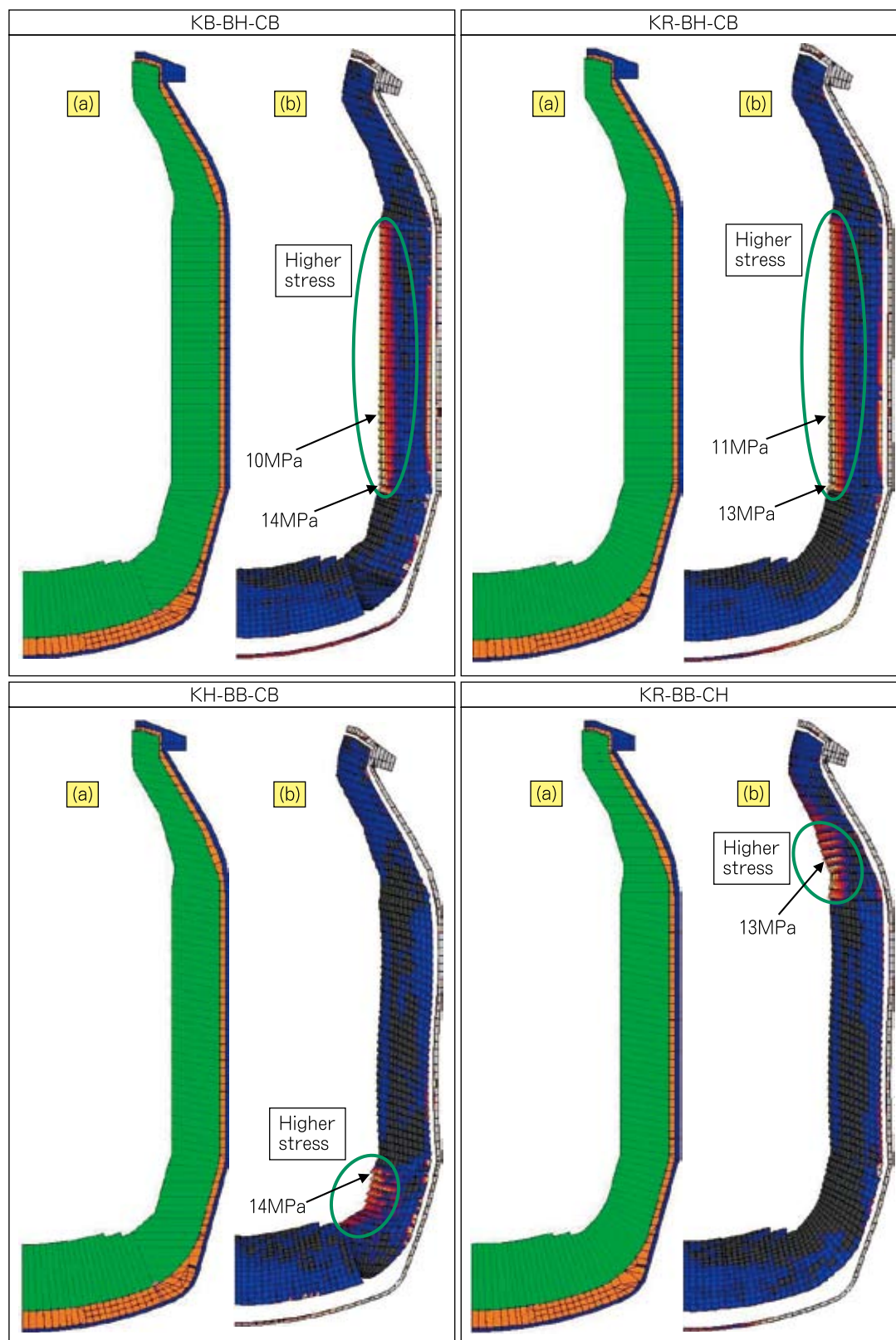


Fig. 4 BOF lining models in which the horizontal and backward inclined linings are applied to various lower knuckle, barrel and cone combinations shown in (a). Stress distribution and intensified deformation shown in (b).

はなく、水平積みの箇所だけに大きな応力が発生している。このことは、それぞれの部位での積み方は他の部位の積み方に影響しないことを示唆している。

5. 傾斜積みと組み合わせたときの逆傾斜積み

水平積みはどの部位にあっても、他の積み方と組み合わせても良くないことがわかったので、残りの組み合わせである傾斜積みと逆傾斜積みの組み合わせを検討した。結果をFig. 5に示す。

逆傾斜積みと傾斜積みの境界部に大きな応力が生じることがわかる。また、傾斜積みを絞り部に適用すると、炉口部でウェアーレンが間に大きな

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

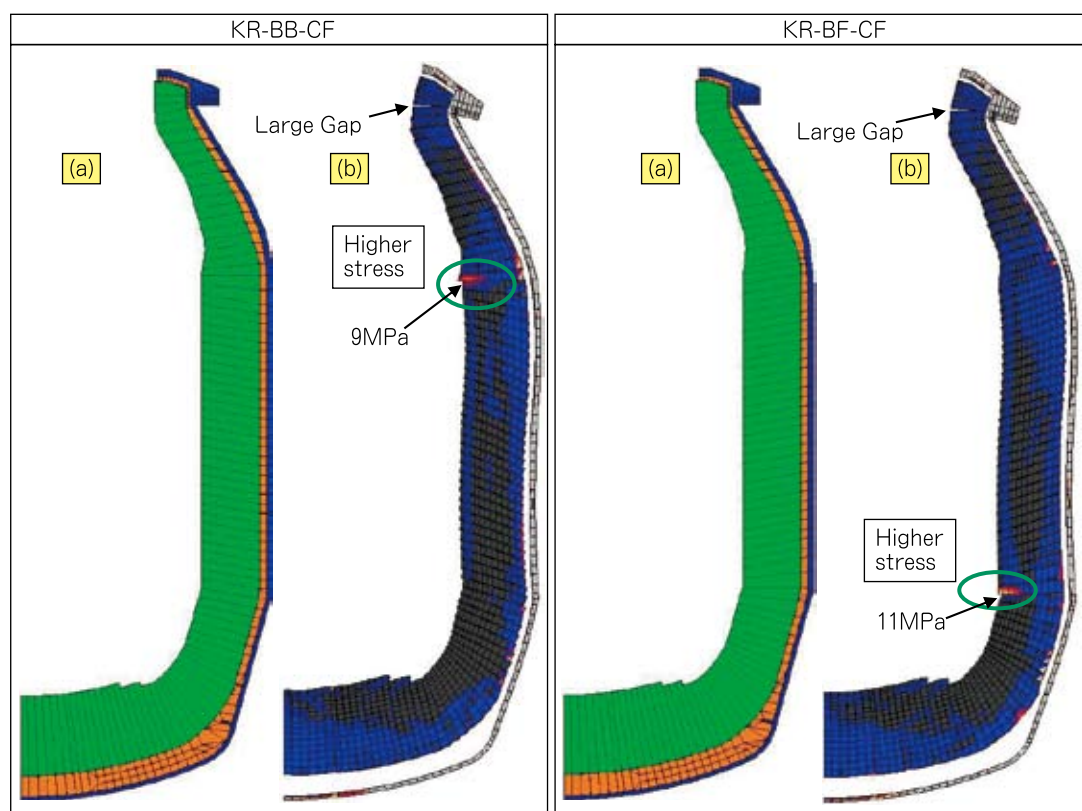


Fig. 5 Lining models of cone: forward inclined, barrel: backward inclined, lower knuckle: round-corner and cone: forward inclined, barrel: forward inclined, lower knuckle: round-corner, as shown in (a). Stress distribution and intensified deformation shown in (b).

隙間が生じることもわかる。隙間には地金が入りやすく、付着地金除去作業時にレンガが脱落しやすくなるので、隙間の生成も望ましくない。

6. 傾斜フルライニング構造

異なる積み方を組み合わせることは良くないことがわかった。そこで、すべてに傾斜積みを適用してみた。結果をFig. 6に示す。

傾斜積みの特徴である炉口レンガが間に隙間が生じていることはFig. 4と同様である。さらに、下部ナックル部の下方に大きな応力が生じていることもわかる。以上のように、この場合も良くないことがわかった。

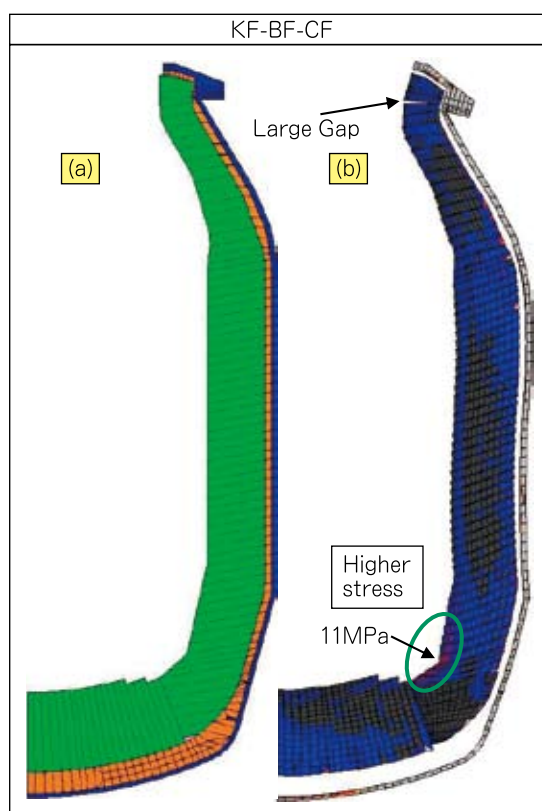


Fig. 6 Completely forward inclined lower knuckle, barrel and cone lining model shown in (a). Stress distribution and intensified deformation shown in (b).

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 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 generated

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			Fig.4
		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			
KF	BH	CH	KF-BH-CH	NG			Fig.6
		CF	KF-BH-CF	NG			
		CB	KF-BH-CB	NG			
	BF	CH	KF-BF-CH	NG			
		CF	KF-BF-CF			NG	
		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			Fig.4
		CF	KB-BH-CF	NG			
		CB	KB-BH-CB	NG			
	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	
KR	BH	CH	KR-BH-CH	NG			Fig.4
		CF	KR-BH-CF	NG			
		CB	KR-BH-CB	NG			
	BF	CH	KR-BF-CH	NG			
		CF	KR-BF-CF		NG		
		CB	KR-BF-CB		NG		
	BB	CH	KR-BB-CH	NG			
		CF	KR-BB-CF		NG		
		CB	KR-BB-CB			Good	

Symbols represented as follows.

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

7. まとめ

以上の結果を含む36ケースの結果をまとめると Table 1 のようになる。

今回の検討により, もっとも理想的なライニング構造は逆傾斜フルライニング構造であり, それは唯一の組み合わせであることがわかった。

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.

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