

転炉絞り部ライニングの新規構造 “逆傾斜積み”

“Backward Inclined Lining”, a New Design for BOF Cone Linings

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Abstract

When bricks drop off from the cone of BOFs, repairing is necessary to continue the campaign. Occasionally, the service life is influenced by the dropping off phenomena. In this study, the cone linings were analyzed with structural analysis technology using F.E.M. to prevent cone bricks from dropping off. Appropriate material data, analysis model and boundary conditions were necessary to obtain highly precise calculation results. It was found that stresses produced in cone bricks and cone brick movement depend on cone lining design. A new design for the cone lining called “Backward Inclined Lining” is presented here which is based on the knowledge about how large stresses and gaps between bricks are produced. In a practical test, the backward inclined lining bricks didn't drop off. Sufficient results were obtained for the new design.

1. はじめに

転炉絞り部れんがは、稼働中及び地金除去作業時に脱落することが多い。そのたびに、補修作業が必要になり、また、時として、炉寿命を低下させることもあり、抜本的解決が求められている。これに対して、以前より脱落防止のための対策¹⁾が種々試みられているが、必ずしも有効な対策とはなっていない。そのような中で、近年、絞り部のライニング構造を水平積みから傾斜積みに変更することにより、比較的良好な結果が得られるようになってきた²⁾。しかし、傾斜積み構造であっても、必ずしも有効でないケースもあり、さらなる対策が求められている。

これまでに、著者らは、従来経験的に採用されていた対策を見直し、そもそもライニング構造とれんが脱落との関係はどのようになっているのかを構造解析技術により明らかにし、ある程度の理論的指針を与えてきた^{3), 4)}。

1. Introduction

Bricks at the cone of BOFs easily drop off during service and during removal of chilled steel. Repairing is necessary each time and service life often deteriorates. Drastic countermeasures have been required. However, some previous countermeasures¹⁾, which have been put to trial until now to control dropping off, aren't always effective. In recent years there has been a trend toward changing the horizontal cone lining to the forward inclined. This has reduced brick drop off²⁾. However, in some cases the forward inclined lining has also been ineffective. Further countermeasures should be taken.

We checked the previous countermeasures which hitherto have been taken from experience. Then, we

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この検討に当たっては、実機の操作条件を十分に考慮した上での、れんが、鉄皮等の材料特性データ、構造解析用モデル、境界条件の設定等のいくつかの重要な要素がある⁵⁾。

本報告では、これら要素に立脚して行なわれた構造解析から新規に得られた「逆傾斜積み」構造を紹介し、実機テストの結果について報告する⁶⁾。

2. 解析条件

2.1 モデル

Fig. 1 に計算に用いた軸対称モデルを示す。このモデ

revealed how the cone lining could be related with brick drop off through structural analysis technology. A guiding principle for taking appropriate countermeasures has been presented^{3), 4)}. Our studies are based on material data of bricks and shell, F.E.M. model and boundary conditions which were obtained while taking operating conditions into consideration⁵⁾.

This report describes the backward inclined lining which was newly obtained with structural analysis based on the above factors and presents the results

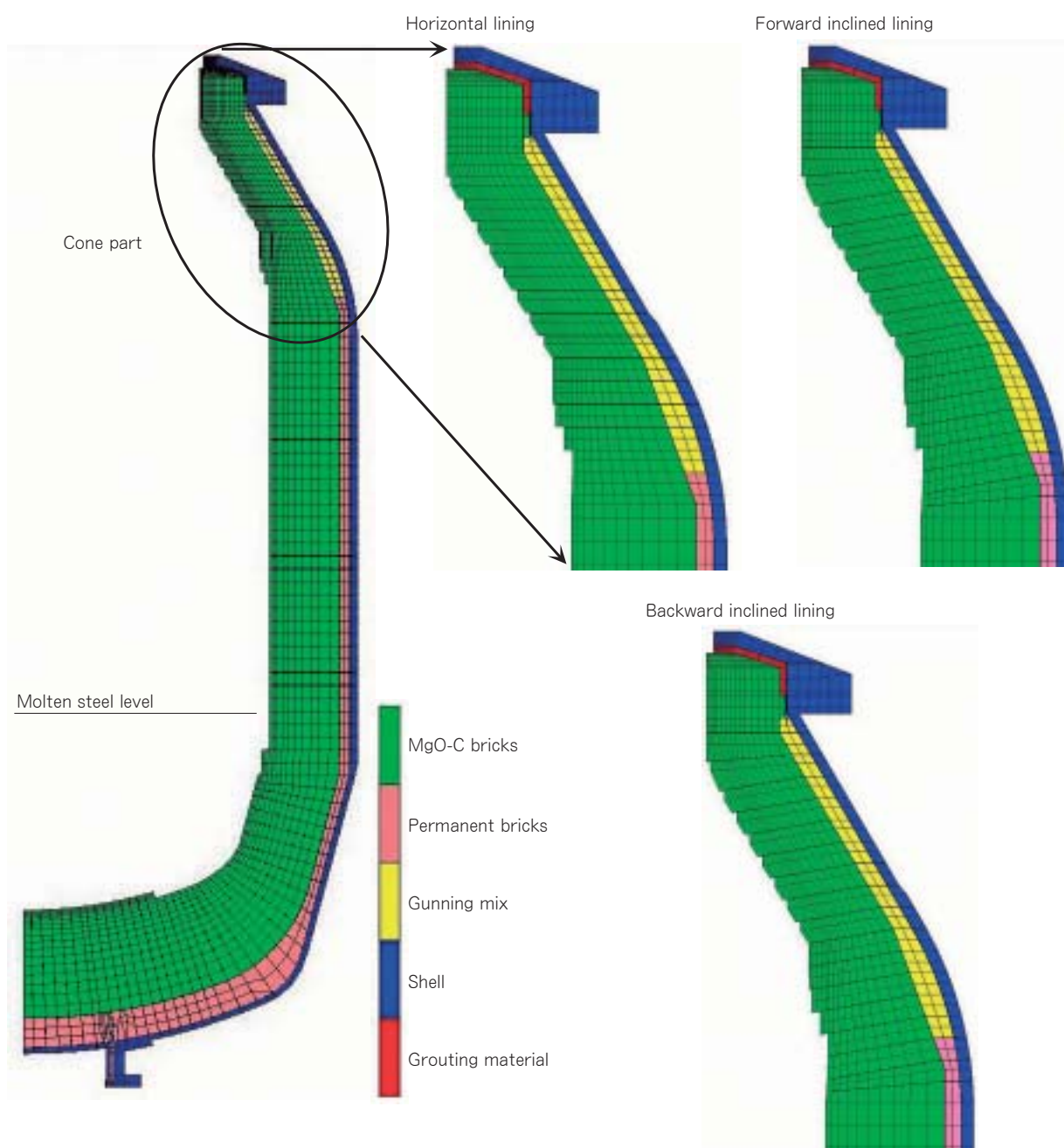


Fig. 1 Axisymmetric model for calculation.

ルに有限要素法を適用した。

高さ方向のれんが積みライニングを対象にして、側壁及び底部は同じライニングであり、絞り部を“水平積み”にした従来積み、その改良である“傾斜積み”，さらに、本報告で提案する“逆傾斜積み”の3種を検討モデルとして主に用いた。

なお、Fig. 1 では、“傾斜積み”及び“逆傾斜積み”の傾斜角度が水平に対して10度であるが、“逆傾斜積み”では5度の場合も検討している。

さらに、“逆傾斜積み”の場合で、起こしれんが（側壁部と絞り部との境界部にあり、れんが積み角度を水平から傾斜に切り替える為のれんが）の検討では、3次元モデルを用いた。

2.2 材料データ

計算を行うには、れんが、鉄皮等についての密度、熱伝導率、比熱、弾性率、熱膨張係数、ポアソン比等のデータが必要である。この内、れんがの熱伝導率、弾性率、熱膨張係数は、熱間で測定したデータを用い、比熱はれんが中の化学組成と単一組成の文献データ⁷⁾とから求めた。ポアソン比は推定値とした。また、鉄皮については、弾塑性体として扱い、降伏点を設定している。

ところで、転炉のウェアれんがであるMgO-Cれんがは不焼成れんがであるので、熱変化を受けて、その特性が変化する。その特徴をここでは取り入れている。一例をFig. 2 に示すが⁸⁾、実際には配材部位ごとに配合状態の異なる。したがって、特性の異なるMgO-Cれんがが適用されている。

2.3 境界条件

Fig. 3 に操業温度条件の一例を示す。

of a practical test⁶⁾.

2. Conditions of Analysis

2.1 Model

Axisymmetric models for calculation are shown in Fig.1. F.E.M.(finite element method) was applied for those models. Linings in which bricks are laid at the bottom, barrel and cone are the subjects for our investigation. Three types of models, which had the same lining at the barrel and bottom, but at the cone a conventional lining - “horizontal”, an improved one - “forward inclined” and a newly developed one - “backward inclined” were made for comparison purposes.

The slope angle of the “forward inclined lining” and the “backward inclined lining” was set at a 10 degree incline. The backward inclined lining was also studied at a 5 degree incline. A 3-dimension model for the backward inclined lining was made to check for moving of barrel cone connecting bricks which were used for connecting the horizontal lining at the barrel to the inclined lining at the cone.

2.2 Material data

Mass density, thermal conductivity, specific heat, elastic modulus, thermal expansion coefficient, Poisson's ratio and so on of the bricks and shell were necessary for computational analysis. The thermal conductivity, elastic modulus and thermal

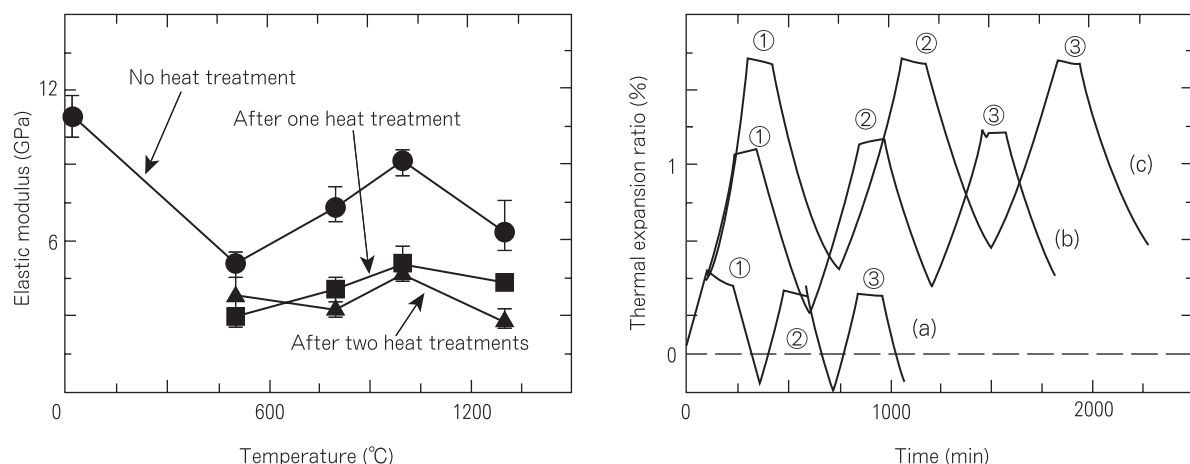


Fig. 2 Example of MgO-C brick data for calculation⁸⁾.

(a),(b)and(c) show from RT to 500°C, 1000°C and 1300°C.

①,②and③show the thermal expansion behavior in the 1st, 2nd and 3rd cycles.

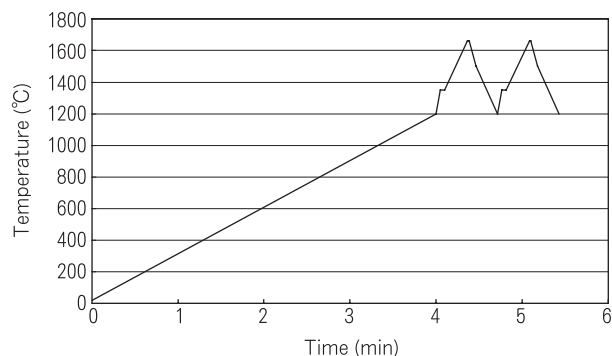


Fig. 3 Example of operating temperature applied to BOF.

施工後、室温から1200℃まで4時間で炉内を予熱昇温し、その後、作業に入っている。溶銑装入から吹錬、出鋼、待機の1サイクル約40分を繰り返す温度条件を適用した。本解析では、炉内温度が概ね定常になる30サイクルまでの計算を行っている。また、炉口フランジ部及び絞り部の鉄皮を水冷、トラニオン側鉄皮を空冷としている。なお、本解析の熱応力計算に先立ち、温度計算が

expansion coefficient of bricks were measured at elevated temperatures for analysis and the specific heat was estimated from the chemical composition of the bricks and specific heat data from a databook⁷⁾ for single chemical composition materials. Poisson's ratio was presumed data. Elastic-plastic analysis was performed for the shell with yield points depending on the elevated temperature.

Properties of unburned MgO-C bricks which were applied to the BOF wear-lining changed with the temperature and heat treatment cycles. Data derived from those property changes were used in the computational analysis.

An example of data is shown in Fig.2. According to the area of the furnace lining, MgO-C bricks of various blending ratios with different properties were applied to actual furnace.

2. 3 Boundary conditions

An operating temperature graph is shown in Fig.3.

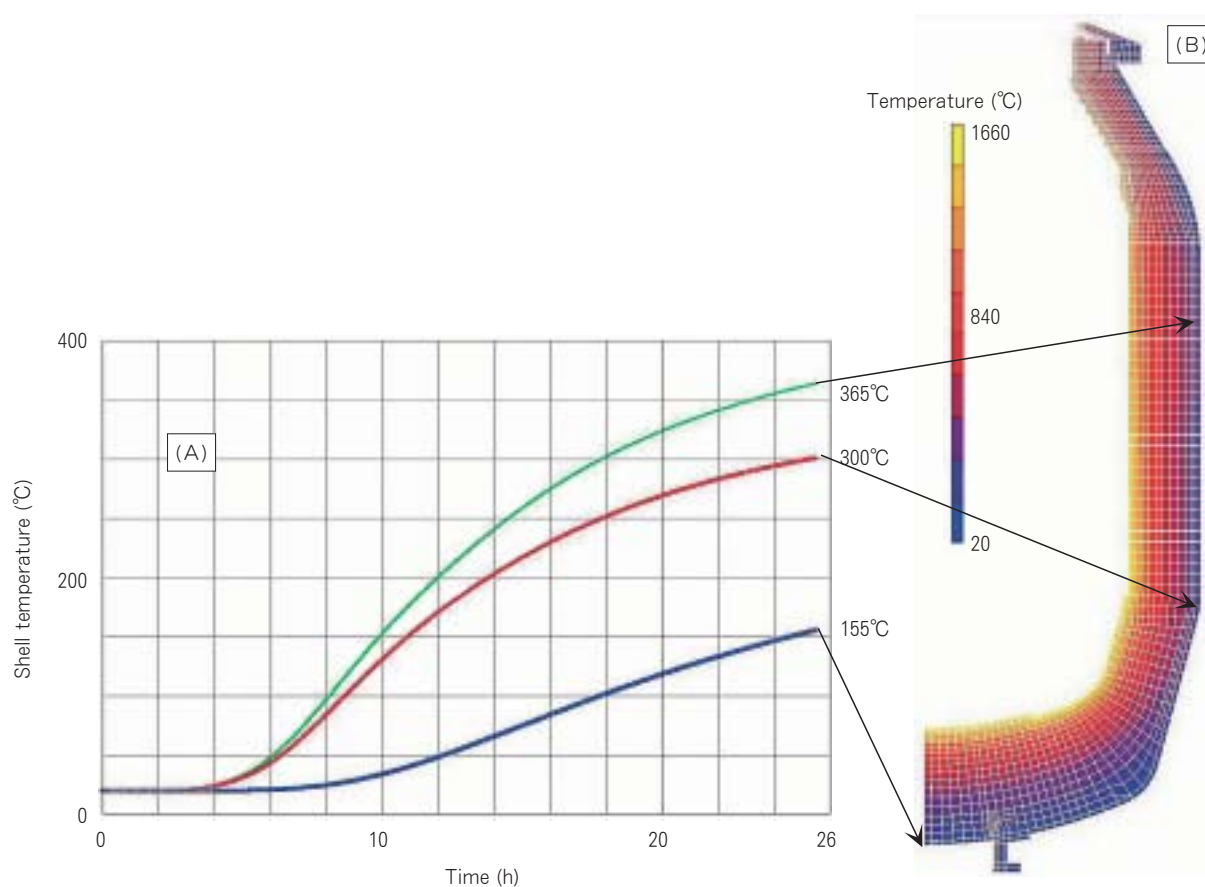


Fig. 4 Shell temperature (A) and temperature distribution (B) obtained by calculation.

行われ、その結果が熱応力計算に利用される。

3. 結果と考察

3.1 温度

Fig. 4 に温度計算の結果を示す。

30サイクル近くの鉄皮温度上昇率から、炉内温度が概略定常状態に近づきつつあることがわかる。熱応力計算は、30サイクルまで行い、その間の応力、変位、変形状態を調べることにした。

なお、鉄皮温度はおおよそ400℃以下であり、実機で得られる鉄皮温度に近い結果になっている。

3.2 絞り部“水平積み”の特徴

Fig. 5 に、絞り部が“水平積み”の場合の応力を示す。

直胴部に近い絞り部付け根付近に大きな応力が生じている。この応力を時間経過で調べると、稼動サイクル毎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ることがわかった。また、各サイクルで応力がピークを示す時期は出鋼直前であり、炉内温度が最も高くなった時期に相当する。すなわち、炉内れんがの膨張が最も大きくなったときがピーク応力になっている。

Fig. 5 (B)は、変形を強調した図にもなっているが、図から分かるように、大きな応力の生じているれんがは

After construction, the furnace was preheated from R.T. to 1200℃ in 4 hours before starting the operation. Operating temperature during the 40 minute cycle of putting pig iron, blowing, tapping and waiting was repeated for calculation. In this present study, computational analysis was performed until 30 cycles after which the temperature in the furnace is normally balanced on the whole.

The mouth flange and the cone shell were cooled by water and the trunnion side shell by air. The results for heat transfer analysis which was firstly performed were used for thermal stress analysis.

3. Results and Discussion

3.1 Temperature

The results for heat transfer analysis are shown in Fig.4.

The shell temperature rising rate near the 30th heating cycle indicated that the temperature of the furnace was in a roughly steady state. By using the temperature results, thermal stress analysis was performed to study the stress, displacement and

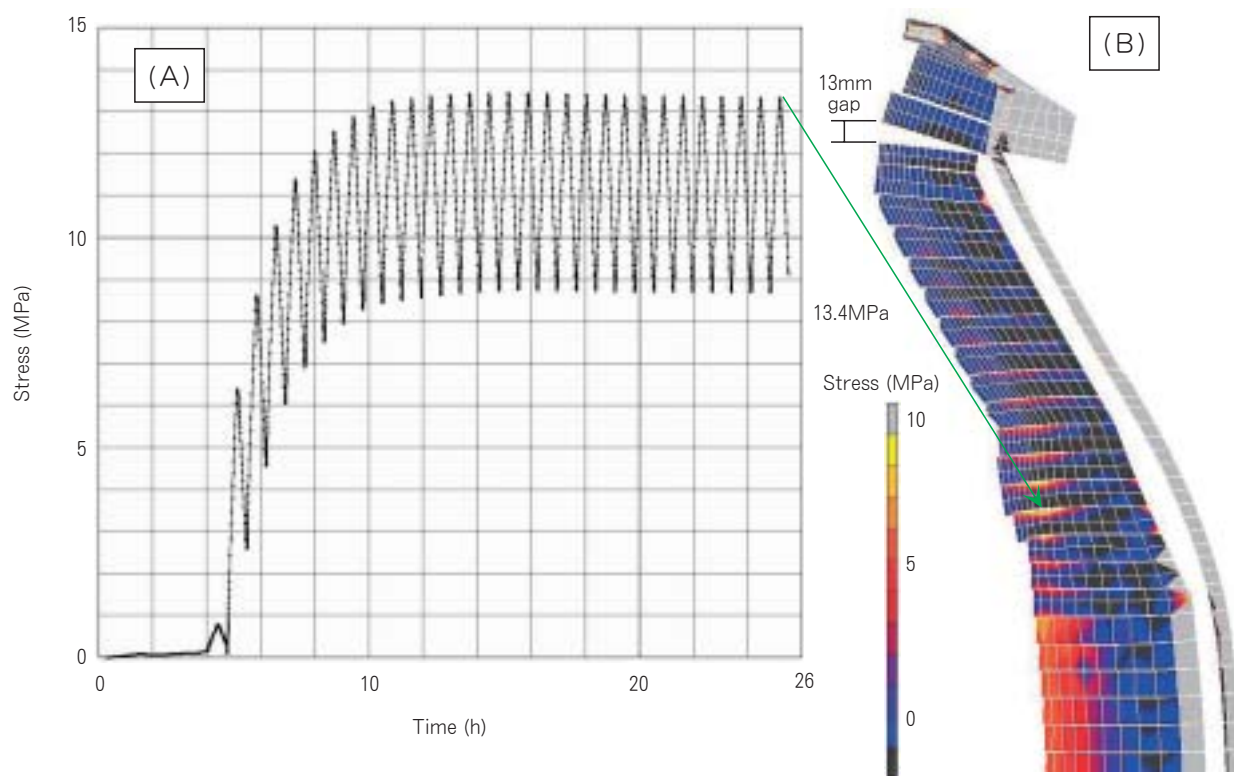


Fig. 5 Transition of higher stress (A), stress distribution and intensified deformation (B) for horizontal lining at cone, just before the tapping of 30th heat — safety lining is eliminated for easy viewing.

上に凸の曲げ変形を受けている。これは、膨張による炉底からの突き上げと絞り部上部からの押さえ込みによって生じた変形である⁹⁾。大きな応力は、この変形によって生成されたと考えられる。したがって、絞り部付け根部からのれんがが損傷されると、その影響による絞り部上部れんがの脱落が予想される。

さらに、炉口付近のれんがには隙間が生じている。隙間には地金が進出しやすく、付着地金除去作業時にれんがが脱落しやすくなるので、隙間の生成も望ましくないことがわかる。

3.3 “傾斜積み”と“逆傾斜積み”の特徴

前節で、“水平積み”の場合、絞り部付け根部を起点にして絞り部れんが全体の脱落及び炉口部れんがの脱落が予想された。そこで、曲げ変形を緩和できる方策として“傾斜積み”と今回新たな検討構造として考えた“逆傾斜積み”に生じる応力等を調べた。結果をFig. 6に示す。

いずれの積み方も、“水平積み”に見られた絞り部付け根付近の大きな応力は生じていない。一方、炉口れんが間の隙間は、“傾斜積み”であっても改善されないが、“逆傾斜積み”では、隙間はなく、膨張によるれんがの挙動がスムーズであったと考えられる。

deformation state during the 30th cycle. Shell temperature was about 400°C, nearly equal to that of an actual furnace.

3.2 Features of horizontal lining

The stress distribution for the horizontal lining at the cone is shown in Fig.5

The stress at the lower part of the cone near the barrel was higher. The stress increased with each operating cycle and attained a constant level after about 10 cycles. Peak stress during each cycle occurred just before tapping when the temperature in the furnace was highest. In other words, when the thermal expansion of the bricks was highest, the peak stress was produced.

An intensified deformation diagram is also shown in Fig.5(B). Bricks in which the higher stress was produced were warped with the middle bowing up. This warp was generated by force pushing up from the bottom and barrel and down from the upper part of the cone⁹⁾. That is to say, this deformation produced the higher stress. If bricks at the lower part of the cone were damaged, those above them

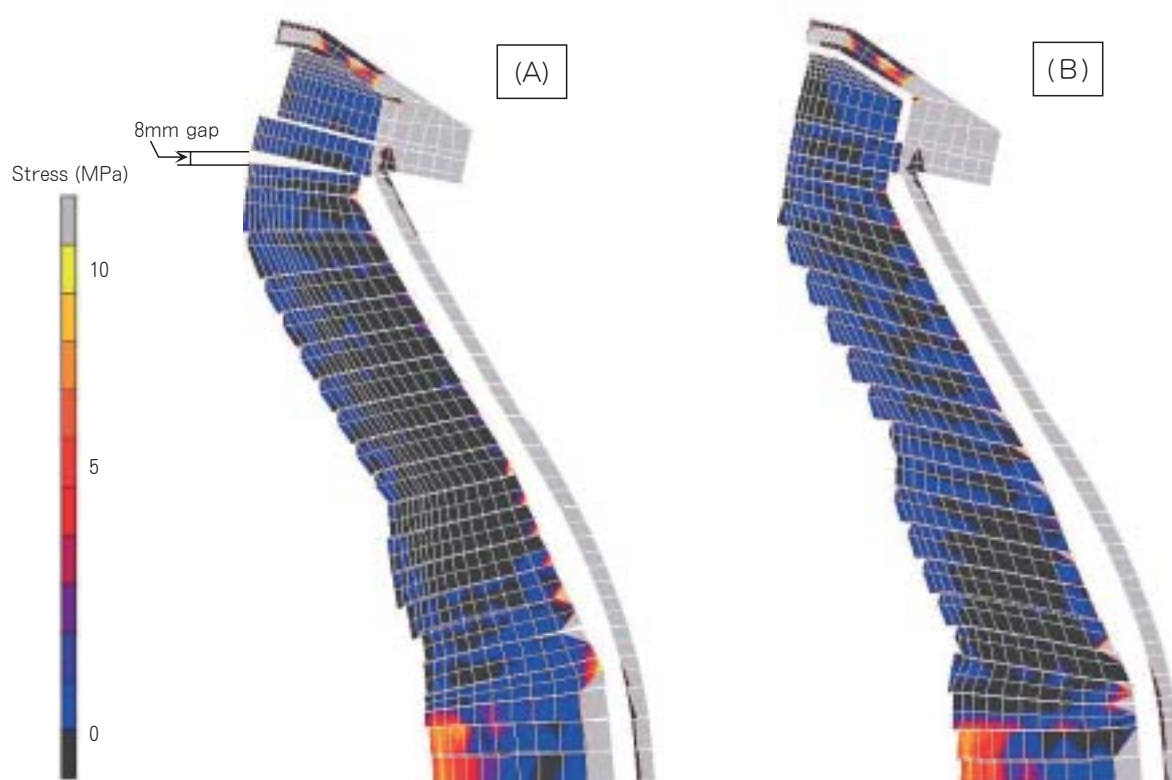


Fig. 6 Stress distribution and intensified deformation for forward inclined lining (A) and backward inclined lining (B) at cone, just before the tapping of 30th heat — safety lining is eliminated for easy viewing.

Fig. 7 に、“傾斜積み”と“逆傾斜積み”の応力緩和の機構及びれんがの相対的な移動方向の概念図を示した。“水平積み”に比べて、いずれの積み方も、れんが積み角度を変えることにより、負荷荷重が分散している。そのために、応力が緩和されると考えられる。また、“傾斜積み”は、れんがの炉内側が炉底方向に鉄皮側が炉口方向に相対的に移動しやすく、一方、“逆傾斜積み”はその逆の方向に移動しやすくなっている。そのような動きに対して、炉口鉄皮は花びらのように開きやすいので (Fig. 6 参照)、“傾斜積み”では、炉口れんがに間に隙間が生じるようになったと考えられる。

3. 4 “逆傾斜積み”の諸課題

前節の検討結果では、“逆傾斜積み”は“水平積み”及び“傾斜積み”よりも良好であることが期待できた。ここでは、“逆傾斜積み”について、いくつか懸念される問題について検討した。

直胴部の水平積みから絞り部の“逆傾斜積み”に移行する境目では、角度を変えるための起しれんがが必要になる。この起しれんがは炉内側の高さ寸法が鉄皮側よりも大きいために（言わば、炉内に向かってラップ状に広がった形状）、炉内に突き出される懸念がある。そこで、

would drop off.

In addition, a gap between the bricks near the mouth was produced. Metal can easily penetrate into such a large gap causing mouth bricks to drop off during the removal of chilled steel, so generation of these gaps should be avoided.

3. 3 Features of forward and backward inclined lining

In the previous section, the results of analysis for the horizontal suggest that all bricks at the cone and mouth fall in when dropping off occurs at the lower part of the cone. The “forward inclined lining” and the “new backward inclined lining” by which it was possible to relax bending in the cone section were analyzed for stresses and so on. The results are shown in Fig.6.

Neither lining had the high stresses which were produced in the cone of the horizontal lining. On the other hand, the gap between bricks at the mouth was not improved by the forward inclined lining. But the backward inclined lining eliminated the gap

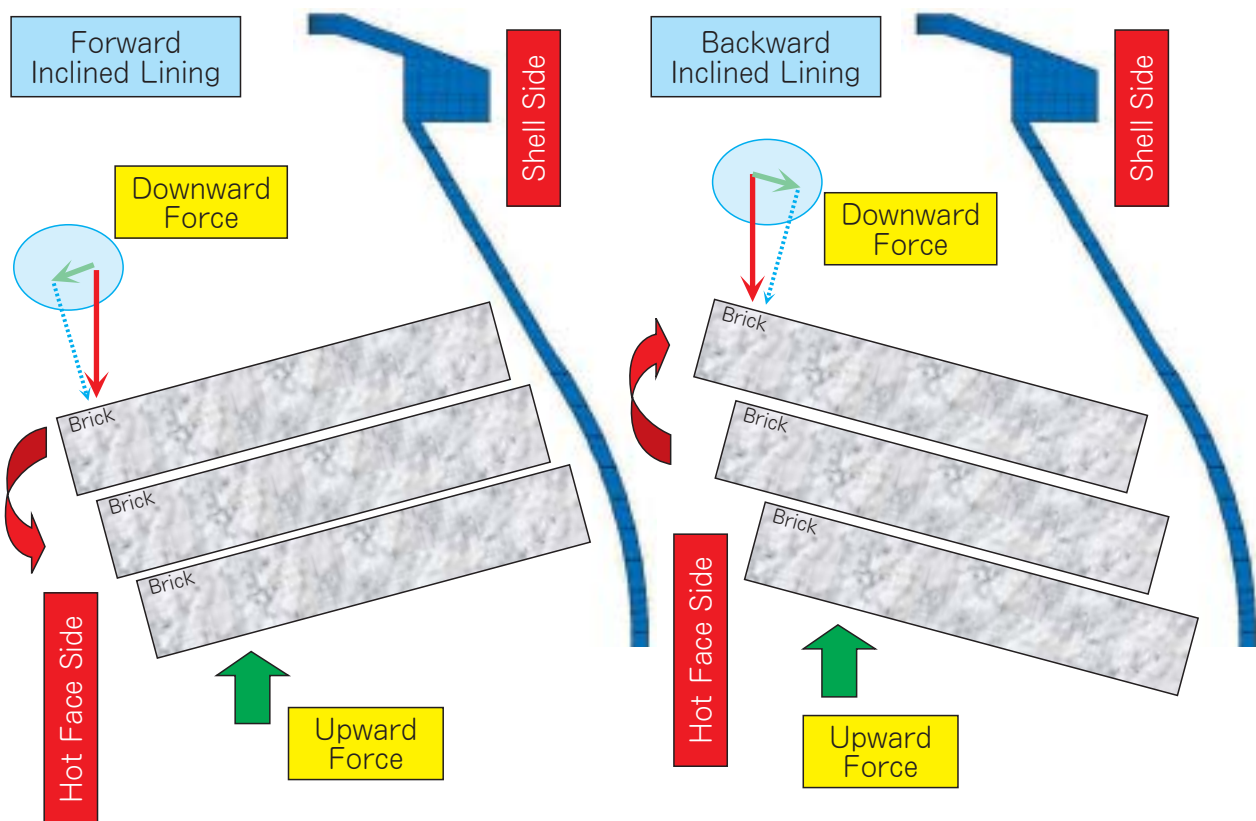


Fig. 7 Mechanism of stress relaxation and bricks movement for the forward inclined lining and the backward inclined lining at cone.

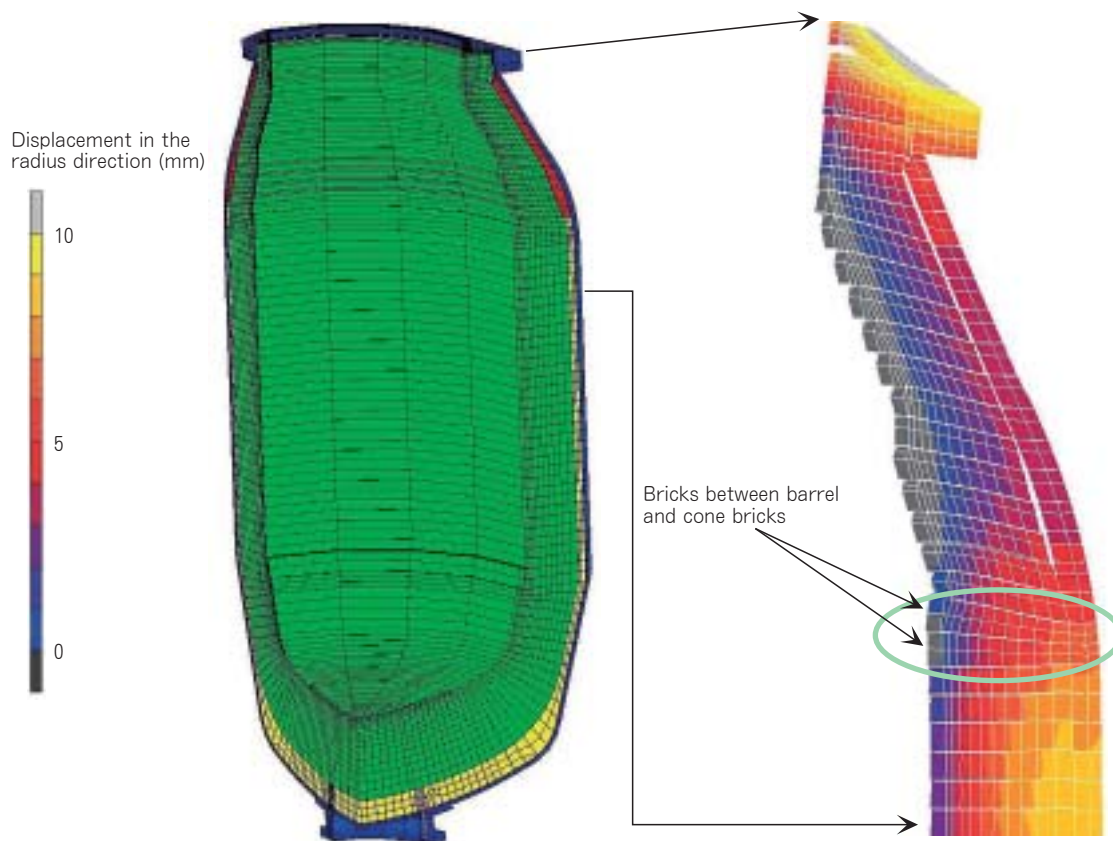


Fig. 8 3D-model to check movement of two brick layers between barrel and cone bricks and displacement in the radius direction for backward inclined lining at cone — safety lining is eliminated for easy viewing.

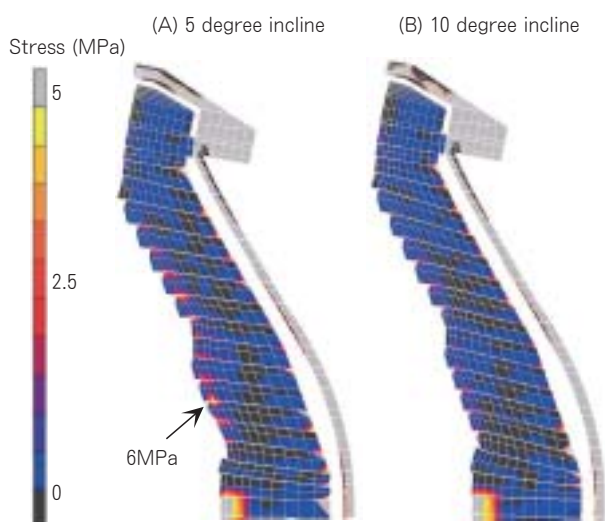


Fig. 9 Stress distribution and intensified deformation for backward inclined lining, just before the tapping of 30th heat — safety lining is eliminated for easy viewing.

この問題を円周方向のれんがの動きも考慮できる3次元モデルで検討した。結果をFig. 8に示す。起こしれんがの稼働面は、その下の直胴部れんが稼働面と比べて、炉

because brick movement caused by thermal expansion was smooth.

The mechanism for stress relaxation and relative movement direction of bricks for the forward and backward inclined linings is shown in Fig.7.

For both linings, the load on bricks laid at an angle was distributed, relaxing the stress. For the forward inclined lining, the hot face of the brick moves downwards and the cold face moves upwards. However, for the backward inclined lining, the opposite movement is realized. As the mouth shell opens like a flower blooming because of the lining movement shown in Fig.6, the forward inclined lining produces gaps between bricks.

3. 4 Subjects of backward inclined lining

Results in the previous section predict that the backward inclined lining is better than the horizontal and the forward inclined. In this section, some problems of the backward inclined lining are presented.

Barrel cone connecting bricks must be used to

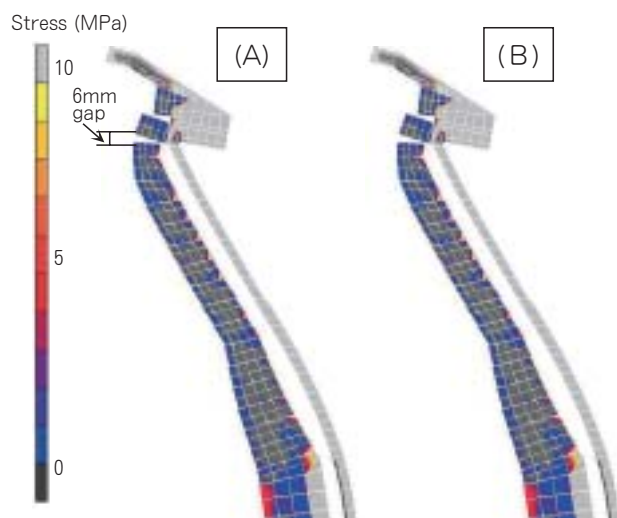


Fig.10 Stress distribution and intensified deformation in last lining profile for forward inclined lining (A) and backward inclined lining (B) at cone, just before tapping. — safety lining is eliminated for easy viewing.

内に突き出る量は2.6mmとほとんど無視できる値であった。すなわち、稼働中において、起こしれんがが炉内に脱落する心配はないと推定された。

つぎに、逆傾斜角度を調べた。結果をFig. 9 に示す。水平面に対して5度の逆傾斜角度では、稼働面付近にやや大きい応力が発生している。“逆傾斜積み”の効果を得るには、10度程度の逆傾斜角度が必要と考えられる。

Fig.10に、残厚約300mmの稼働中期ライニングプロフィールを用い、“傾斜積み”と“逆傾斜積み”の効果を検討した結果を示す。ほぼ稼働初期の状態と同様の結果が得られた。すなわち、“逆傾斜積み”は、稼働の全期間を通じ効果が期待できると考えられる。

4. 実機テスト

Fig.11に、“逆傾斜積み”を鹿島製鉄所にて実機テストしたときの施工の様子及び使用直後の炉内の様子を示す。

本炉は、通常は炉口から脱落が開始し、その後、絞り部の上から下に向かって順次脱落が広がる特徴を持っている。しかし、Fig. 1 に示す“逆傾斜積み”を適用した結果、炉口3段は脱落したものの、それよりも下部の絞り部れんがの脱落はなく、安定的な稼働が得られた。

“逆傾斜積み”の効果が得られたと考えられる。

5. まとめ

転炉絞り部に関する構造解析を行い、絞り部のライニ

connect the horizontal lining at the barrel to the backward inclined lining at the cone. They might be pushed out of the working side because the height of the hot face of the bricks is larger than the cold face. The shape expands like a trumpet on the hot face side. A 3D model which could take the influence of bricks in the circumference direction into consideration was made to solve the problem. The results are shown in Fig.8. When the hot face position of a barrel cone connecting brick was compared with that of a contacting barrel brick, the brick was pushed out only by 2.6mm in the direction of the furnace inside which can be ignored. Accordingly, barrel cone connecting bricks will not drop off from the hot face during campaign.

Next, the angle for the backward inclined lining was studied as shown in Fig.9. When the backward inclined lining was angled at 5 degrees from the horizontal, a little higher stress was produced near the hot face. In order to obtain the positive effects of the backward inclined lining, a 10 degree backward facing grade is appropriate.

A wear profile of the lining with a residual thickness of 300mm was used to study the forward and backward inclined linings at the middle of the campaign, as shown in Fig.10. The results were almost the same as at the beginning of the campaign. The backward inclined lining shows good stable results all during the campaign.

4. Test in Actual Furnace

An actual test for the backward inclined lining was performed at Kashima Steelworks of Sumitomo metal industries, Ltd. Photographs of construction and inside just after used are shown in Fig.11.

This furnace shows a typical damage pattern for a conventional lining such that the drop off of bricks starts from the mouth and spreads out over the upper and lower parts at the cone in sequence. However, the backward inclined lining shown in Fig.1 contributed to realizing a stable campaign because the cone bricks didn't drop off at all, and only 3 levels of the mouth fell in. So the backward inclined lining is predicted to be extremely effective.

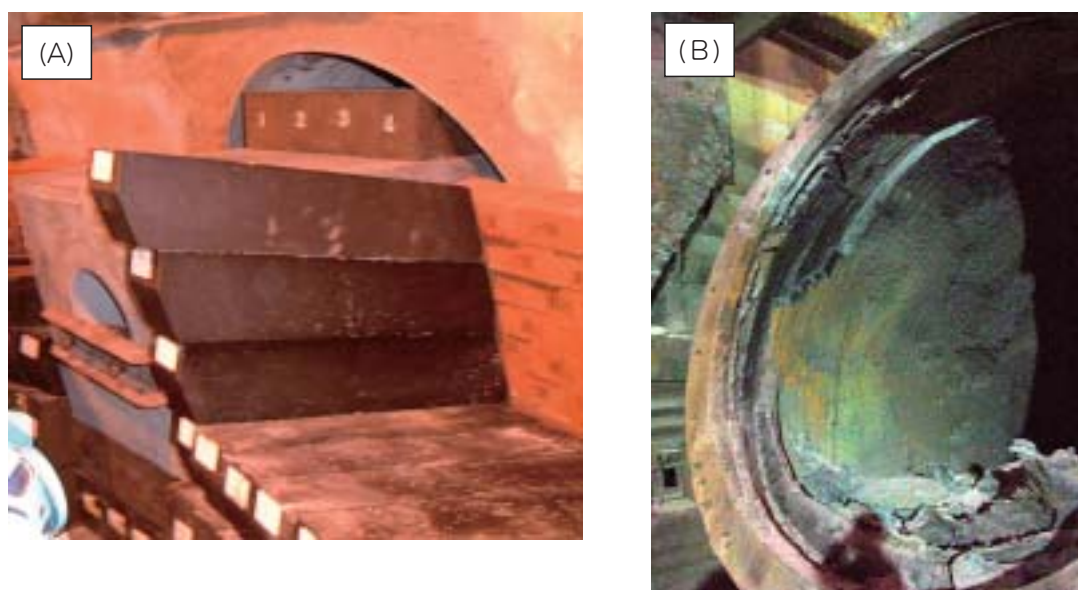


Fig.11 Photographs of backward inclined bricks being laid near tap hole in BOF (A) and the appearance of the cone just after use (B).

ング構造とれんが脱落との関係の特徴づけることができた。その知見をもとにして、新規構造の“逆傾斜積み”構造を提案することができた。実機テストでは、従来構造では、絞り部の脱落が生じていたが、“逆傾斜積み”では絞り部れんがの脱落はなく、良好な結果を得ることができた。

5. Conclusion

By performing structural analysis on the BOF cone lining, the relationship between the cone lining and brick drop off was made clear. On the basis of that knowledge, we newly presented “the backward inclined lining”. The backward inclined lining bricks in the actual test didn't drop off, although the conventional lining bricks at the cone dropped off. Sufficient results were obtained for the new design.

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