

加古川 1 RHにおける下部槽寿命の改善*

Improvement of Campaign Life of No.1RH Lower Vessel in Kakogawa Works

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Abstract

In order to satisfy higher quality steel requirements, No.3RH degasser was installed in Kakogawa works in November 2004. After the start of No.3RH operation, heats per day of existing No.1RH have been decreased and the ratio of high-quality steel, which requires long treatment time, has increased. With such a considerable change in service conditions, the campaign life of No.1RH lower vessel has sharply decreased to a low level due to heavy wear of the bottom bricks and unusual wear of the throat bricks which results in the sudden shut down of the vessel. In order to reduce the wear rate of the bottom bricks, repairing procedures and bottom brick material have been improved. In addition, to preventing unusual wear of the throat brick, expansion allowance of the bottom bricks has been improved by using refractory cushion board while carefully managing bottom shell deformation. With these improvements, wear rate of the lower vessel has markedly decreased and sudden shut downs caused by refractory troubles have also been reduced. This paper describes these No.1RH refractory improvements and gives a structural analysis of the vessel lining which is ongoing.

1. はじめに

加古川製鉄所では薄板ハイテンなどの高級鋼の増加に対応するべく、No. 3 RH設備を2004年11月に稼働させた。No. 3 RHの稼働により、取鍋精錬プロセスが各連铸機と整合化するようになり、物流が大きく改善された (Fig. 1)。No. 3 RHが稼働するまでは、No. 1 RHでほとんどを処理し

1. Introduction

In order to meet requests for upgrading steel quality, such as high tensile steel, new No.3RH was installed in Kakogawa works in November 2004. After the start of No.3RH operation, the ladle refining processes were matched with the continuous casting

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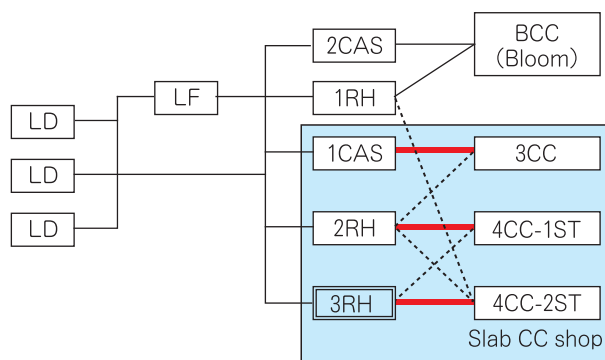


Fig. 1 Change in process flow with No.3RH operation in Kakogawa Works.

ていた4CC-2ST向け厚板鋼種は、今やそのほとんどがNo. 3 RHで処理されることになった。これに伴い、現在No. 1 RHでは1日あたりの処理チャージ数が減少し、主製品は線材向け鋼種の処理が中心となっている。No. 1 RHの1日当たりの処理チャージ数が減少する一方で、長い時間処理が必要な高級鋼の比率は増加しており、このためNo. 1 RHの平均処理時間は増加傾向にある (Fig. 2)。

2. No. 1 RHにおける寿命の低下

このような操業条件の大きな変化に伴い、No. 1 RHでは槽底れんがの損傷や環流管れんがの異常損傷が原因になって、下部槽寿命が大幅に低下した。Fig. 3 にNo. 1 RHにおける下部槽寿命の推移を示す。側壁れんがの材質改善や昇熱時の送酸量管理により、No. 1 RHの寿命は500chまで増加していた。しかし、No. 3 RHの稼働に伴い下部槽寿命の低下が始まり、'05年/下期では450chに満たずに停炉するケースがある。従来は下部槽のもっとも損傷が大きな部位は側壁であったが、現在では槽底と環流管れんがの損傷がもっとも大きくなっている。そこで、その損傷状況と原因について、従来からの変化点を中心に調査を行った。^{1), 2)}

3. れんがの損傷状況とその対応

下部槽寿命の低下は槽底れんがと環流管れんがの激しい損傷に原因がある。そこで、れんがの損傷状況を各ケースごとに調査した。

3. 1 槽底れんがの損傷状況

使用チャージ数と槽底れんがの残厚の変化を Fig. 4 に示す。グラフの各プロットは浸漬管交換

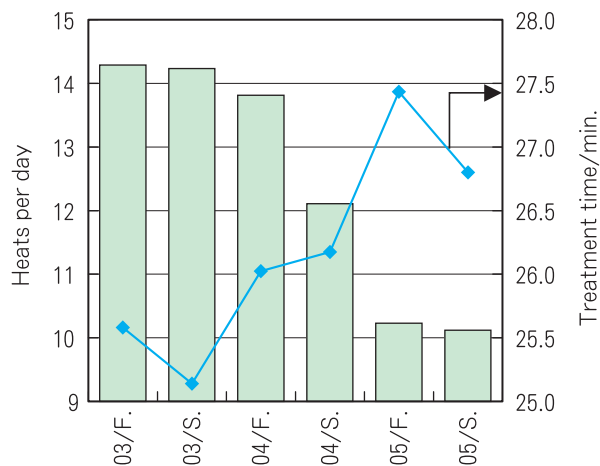


Fig. 2 Change in heats per day and treatment time at No.1RH.

machines, and physical distribution improved. (Fig.1)

Up to the start of No.3RH operation, most plate steel for 4CC-2ST was treated at No.1RH, and now, most of it is treated at No.3RH, therefore, heats per day in existing No.1RH have decreased and the main product of No.1RH has been changed to steel wire rod. Though, heats per day in No.1RH has decreased, the ratio of high-quality steel which requires long treatment time has increased, so the average treatment time in No.1RH has increased. (Fig.2)

2. Reduction in Campaign Life of No.1RH

With such a great change in the service conditions, the campaign life of the lower vessel has decreased because of bottom brick wear and unusual throat brick wear in No.1RH. The change in campaign life of the lower vessel of No.1RH is shown in Fig.3.

By improving the sidewall brick material and controlling the amount of O₂ blowing during heatup, the campaign life of No.1RH was increased to 500heats. However, after the start of No.3RH operation, it has started to decrease, and in second half of '05, there were some cases that end within 450heats. Formerly, the most critical wear area of the lower vessel was the sidewall, but now, is the

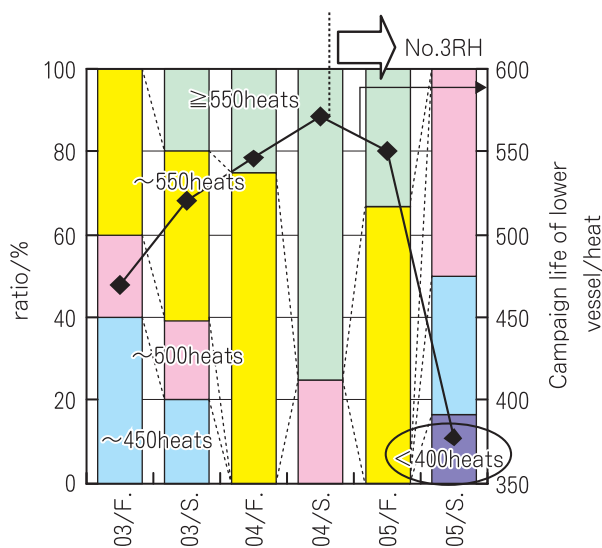


Fig. 3 Change in campaign life of the lower vessel in No.1RH.

ごとに測定した下部槽槽底れんがの残厚を示している。Fig. 4 のデータは、No. 3 RH稼働前の'04年下期と稼働後の'05年上期の2種類からなっている。槽底れんがの残厚は、トラブル防止の観点から、下部槽稼働の最後で100mm以上を確保することになっている。従来と比較して3 RH稼働後の'05年上期は、槽底れんがの損傷速度は全体的に大きくなっている。また、これまでも停炉までに槽底れんがの残厚が100mm以下となるケースは発生しているが、その発生頻度は以前よりも高くなっている。圧入補修材、槽底れんがそれぞれについて損傷速度を調査したところ、いずれについてもNo. 3 RH稼働後の損傷速度は以前よりも増加していることが確認できた。

3. 2 槽底れんがの損傷状況と改善

槽底れんがおよび圧入材の損傷速度が大きくなった原因としては、①処理時間の増加に伴い槽底および環流管れんがの損傷が大きくなっていること、②稼働率の低下に伴う温度変化により、スポーリング損傷が発生していることが考えられる。まずは、応急的な対応として、圧入補修のスパンを短縮した。従来、浸漬管耐火物の寿命となる約100chを目安に、浸漬管交換と併せて圧入補修を実施してきた。しかし現在は、オペレーターが各チャージ処理後に圧入材の残存状況を目視確認し、状態が良くなければ、浸漬管の状況に関係なく補修する体制をとり、トラブル防止を図っている。恒久対策としては、槽底れんがの材質をマグクロレンがから耐スポーリング性に優れるマグカーボ

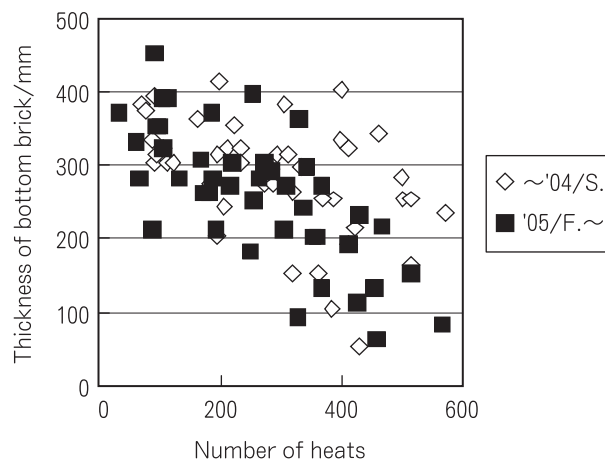


Fig. 4 Change in bottom brick thickness with No.3RH operation.

bottom brick area and the throat brick area. Therefore, the conditions and the reasons were investigated, centering around the change in service conditions.^{1), 2)}

3. Wear Condition of Bricks and Countermeasures

The reduction in the campaign life of the lower vessel is due to the severe wear of the bottom bricks or the throat bricks. So, the wear condition of the bricks was investigated in each case.

3. 1 Wear condition of the bottom bricks

The change in bottom brick thickness with the number of heats is shown in Fig.4. Each point on the graph shows the thickness of the bottom bricks, which was measured during the snorkel change. The data in Fig.4 consists of two types, data during the second half of '04 before the start of No.3RH operation and data during the first half of '05 after start. The thickness of the bottom brick is required to be at least 100mm at the end of lower vessel campaign for trouble free operation. Compared with the former level, the wear rate of the bottom bricks in the first half of '05 is quite rapid. There are some cases where the thickness of the bottom bricks falls below 100mm by the end of each term. The frequency is higher than before. Investigation of the wear rate of pressure

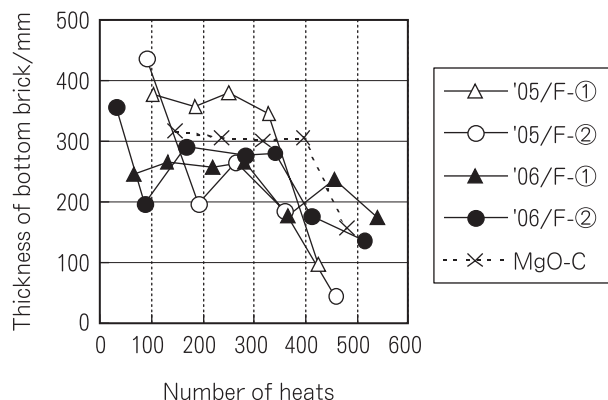


Fig. 5 Change in bottom brick thickness at No.1RH.

ンれんがに変えることである。改善実施後の槽底残厚の推移グラフをFig. 5に示す。これらの改善により、下部槽の停炉まで残厚100mmを確保することが可能になっている。

3. 3 環流管れんがの損傷状況

Fig. 6に環流管れんがの損傷による槽底鉄皮穴あきトラブル発生時の、環流管れんがの損傷部位外観を示す。鉄皮の穴あき位置は上昇側環流管と槽底鉄皮との接合部分であった。さらに、亀裂は下降側環流管のれんがにも半周に渡って認められた。それらはまた、激しく損傷されていた。

そこで損傷の程度と原因を探るべく、停炉後の下部槽の調査を行った。まず、下部槽の敷きれんがの状況を観察したところ、まったく損傷していないことがわかった。敷きれんがを解体していくと、上昇管から下降管にかけて、槽底の鉄皮とれんがの間に地金差しが認められた。そこで、環流管れんがの損傷部位を詳細に調査した。損傷された環流管れんがの切断面をFig. 7に示す。れんがには、稼働面から背面にかけ、いくつかの亀裂が発生している。それらの亀裂の方向は稼働面に垂直ではなく、また、互いに平行でもない。このことより、環流管れんがに何らかの応力が生じて亀裂が発成し、続いて、その亀裂に溶鋼が侵入し、終には、鉄皮穴あきが起こったと考えられる。

3. 4 環流管れんがの損傷状況とその改善

環流管れんがに応力が発生するメカニズムは、①槽底れんがの熱膨張による場合と、②下部槽鉄皮の変形による場合の2つが考えられる。そこでまず、槽底れんがの熱膨張による影響について検討を行った。

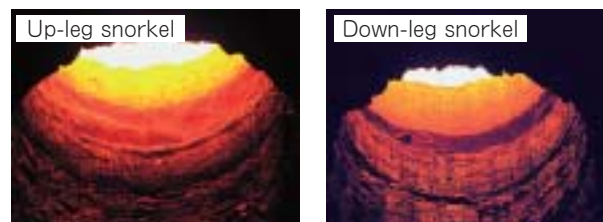


Fig. 6 Appearance of damaged throat brick.

grouting refractory material and of bottom bricks revealed that the wear rate after the start of No.3RH operation is faster than that before the start.

3. 2 Wear condition of the bottom bricks and improvement

The reason for the increase in the wear rate of the bottom bricks and pressure grouting refractory material is thought to be ① Increase in treatment time causes severe wear of the bottom and throat leg, ② Spalling as a result of temperature changes caused by decrease in heats per day. At first, as a temporary measure, the grouting repair span was shortened. As usual, grouting repair was carried out during snorkel exchange, depending on the snorkel life of almost 100heats. But now, the condition of the grouting material is observed after every treatment by the operators, and if the condition is bad, grouting repair is carried out regardless of the snorkel condition, in order to avoid trouble. As a permanent measure, the material of the bottom brick will be changed from magnesia-chrome to magnesia-carbon, in the future to decrease spalling damage. The change in bottom brick thickness after the improvements is shown in Fig.5. With these improvements, the thickness of the bottom brick remained over 100mm until the end of the lower vessel life.

3. 3 Wear condition of the throat bricks

The appearance of the damaged throat bricks, that caused the perforation of the bottom shell, is shown in Fig.6. The perforated area was the part connecting the upleg snorkel with the bottom shell of the lower

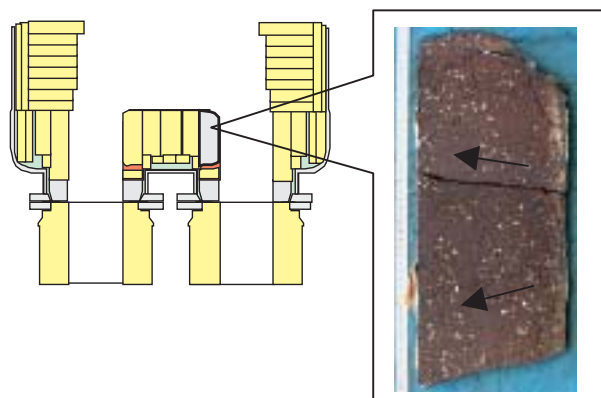


Fig. 7 Cross section of damaged throat brick.

3. 4. 1 膨張吸収代の改善

加古川製鉄所では、下部槽にはリング形状の環流管ライニングを採用している。環流方向、反環流方向について、槽底れんがが熱膨張したときの、膨張吸収代を概算した。なお、れんがの膨張量はマグクロれんがの膨張率（1.37%）を使って計算した。また、膨張吸収代は鉄皮缶体の膨張とモルタル目地のクリープを考慮して、以下の式で膨張吸収率を計算した。

$$\text{れんが膨張量} = \text{槽底れんが施工径} \times \text{れんが膨張率 (1.37\%)} \quad \cdots (1)$$

$$\begin{aligned} \text{膨張吸収代} = & \text{缶体径} \times 1.08 / 100000 \times \\ & (360^\circ\text{C} - 30^\circ\text{C}) + \text{目地数} \times 2\text{mm} \times \\ & \text{モルタルクリープ率 (20\%)} \quad (2) \end{aligned}$$

$$\text{膨張吸収率 (\%)} = (2) / (1) \times 100 \quad \cdots \cdots \cdots (3)$$

まず、現状の槽底ライニングにおいては、環流方向の膨張吸収率が約50%であるのに対し、反環流方向は37%しかないことが明らかになった。この膨張吸収率に明確で妥当な指標はないが、低すぎると敷のれんがが膨張でせり上がり、これにより環流管れんがの背面側が引上げられて引張応力を生成すると考えられる。そこで、膨張代を改善する目的で、Fig. 8に示すように、敷部のウェアれんがと側壁パーマれんが間に可撓性ボードを設置した。膨張吸収率は環流方向で63%に改善ができた。

3. 4. 2 下部槽鉄皮の変形とその改善

RHの下部槽鉄皮は、長年の使用により変形するとともに、2つの環流管がハの字に変形する現象が発生する。そこで、下部槽鉄皮の変形を定量的に評価するために、1炉代使用毎に下部槽鉄皮の変形量測定を実施した。変形量測定方法は、下部槽の上端から槽底鉄皮までの距離を、Fig. 9に

vessel. Furthermore, a crack extended half-way around the throat bricks in the downleg snorkel. They were also severely damaged.

In order to investigate the degree of damage and cause, we carefully examined the lower vessel after service. At first, the bottom brick condition of the lower vessel was observed and found not to be damaged at all. As the bottom brick is demolished, the finning was found between bottom shell and bottom brick, from upleg to downleg. So, damaged throat brick was examined in detail. The cross section of a damaged throat brick is shown in Fig.7.

In that brick, there are some cracks from the hot face to the cold face. They are not normal to the hot face, and they are not parallel to each other. From these results, it seems that, some stress occurred in the throat bricks causing the cracks, and then, steel invaded the cracks and the shell was perforated.

3. 4 Wear condition of throat bricks and improvement

Two mechanisms of the throat brick stress were considered, ①the volume expansion of the bottom brick causing the throat brick to spall, ②steel shell deformation of the lower vessel causing the throat brick to spall. First, the influence of the volume expansion of the bottom brick was examined.

3. 4. 1 Improvement of expansion allowance

In Kakogawa works, a ring type throat lining is employed on the lower vessel. The expansion allowances of the volume expansion in the circumferential direction and the other directions were estimated. Then, the expansion amount of brick was calculated using the expansion rate of the magnesiochrome, 1.37%. The expansion allowance is considered to be the expansion of the steel shell and the creep of the mortar joints.

$$\text{expansion amount of bricks} = \text{bottom brick installation diameter} \times \text{expansion rate (1.37\%)} \quad \cdots \cdots \cdots (1)$$

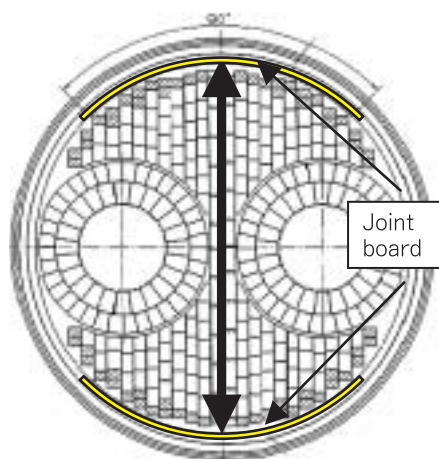


Fig. 8 Expansion allowance of bottom brick.

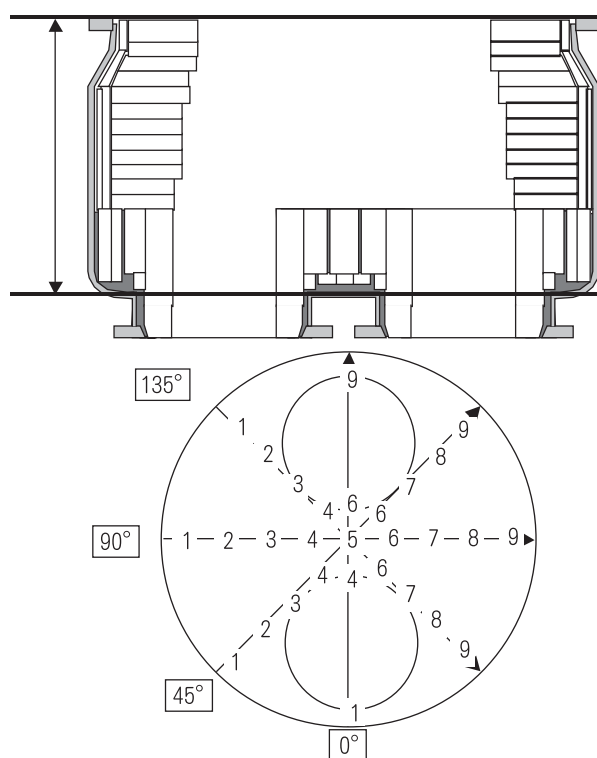


Fig. 9 Measured deformation of the bottom shell after steel shell replacement.

示すように、4方向、各9点（0°部分は5点）について測定する方法を採用した。測定データの一例をFig.10に示す。縦軸は鉄皮図面寸法からの変形量を、横軸は槽底の測定点を示している。変形量は槽ごとに異なるが、この鉄皮においては2炉代の使用で、槽底部分が約45mm変形している。そこで、この鉄皮の変形に関する応急的な措置として、槽底鉄皮の変形限界値を設定し、60mmと

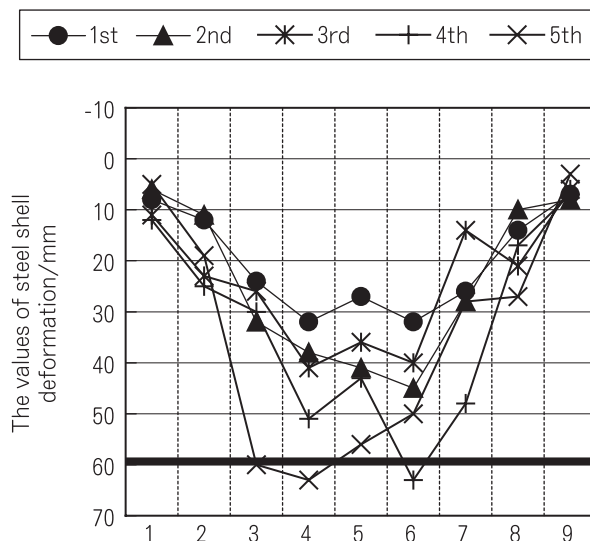


Fig.10 Measured deformation of the bottom shell and limit deformation level.

expansion allowance=steel shell diameter
 $\times 1.08/100000 \times (360^{\circ}\text{C} - 30^{\circ}\text{C}) + (\text{number of joints} \times 2\text{mm} \times \text{mortar creep rate (20\%)}) \dots\dots\dots(2)$

expansion allowance ratio(%) = (2)/(1)
 $\times 100 \dots\dots\dots(3)$

In the usual bottom brick lining, it was revealed that the expansion allowance in the circumferential direction is almost 50%, and that in the other direction is only 37%.

Though there is no determined correct amount for this expansion allowance, it seems that low allowance causes the bottom bricks to bulge up and the cold face of the throat brick is pulled up causing tensile stress. Therefore, in order to improve the expansion allowance, a joint board was set between the wear bricks and the safety lining bricks of the sidewall in the bottom area as shown in Fig.8. The expansion allowance ratio of circumferential direction improved to 63%.

3. 4. 2 Deformation of the bottom shell and improvement

In the RH lower vessel, deformation of the steel shell bottom takes place after long use, and the two throat legs also expand. In order

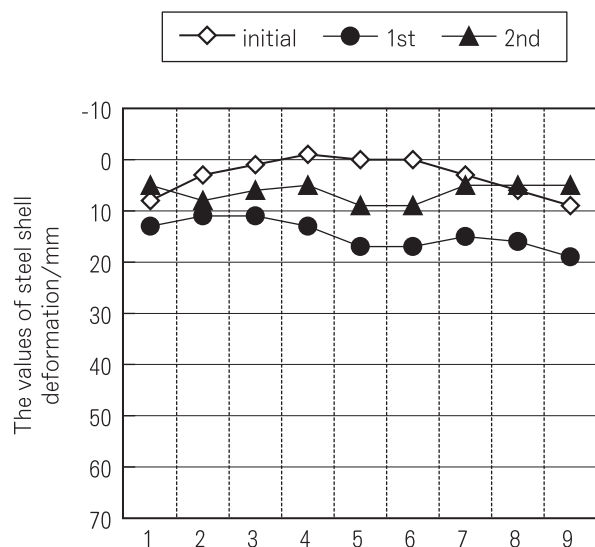


Fig.11 Measured deformation of the improved bottom shell.

した。それは、過去数年に渡って、鉄皮変形が60mm以上の場合に鉄皮更新が必要になるトラブルが多く発生したからである。最良の対策は、鉄皮材質に応じた鉄皮変形量の管理を行うことである。これまでは下部槽鉄皮の材質として、SS400を使用していたが、クリープ変形を抑える目的で、耐クリープ特性に優れた材質を適用することとした。新鉄皮材質の変形挙動をFig.11に示す。従来の材質と比べて、1炉代での変形量絶対値が少なく、またその後の使用でも変形がほとんど進行していない。その結果、鉄皮を更新する際は、この耐クリープ鋼を適用することにした。

4. 改善結果と今後の課題

以上の各種改善を実施してきた結果、Fig.12に示すように、下部槽寿命は従来レベルまで回復した。そして、問題部分の損傷は減少し、トラブルによる突発停炉も低減することができた。

しかし、これらの対策は、環流管の損傷が環流管に生じる応力によって引き起こされるという仮定に基づいている。そこで、これまでの対策の妥当性を明らかにし、また適切な恒久対策を検討するうえで、下部槽に生じる応力の発生メカニズムを定量的に評価することが必要であると考えられる。現在、下部槽の環流管れんがを中心に応力解析を進めている。計算には、温度に従って変化する鉄皮とれんがの両方の特性を考慮している。この解析では、実機で亀裂の生じたれんが箇所と比較的大きな応力が生じており、この大きな応力は、

to assess the deformation of the steel shell bottom quantitatively, displacement of the bottom shell after each campaign was measured. The procedure used for measuring the deformation were the distance from the top of the vessel to the shell bottom, in four directions, for nine points, as shown in Fig.9.

An example of measured data is shown in Fig.10. The axis of ordinate shows the measured displacement from the dimensional plane of the steel shell, the axis of abscissa shows the measured point of the bottom. As the deformation level differs among vessels, there exists about 45mm deformation of the bottom part of this steel shell after two campaigns. As a temporary measure for this deformation of the steel shell, a deformation level limit of 60mm was set because, over the past several years, there have been some troubles of steel shell deforming over 60mm which demanded steel shell renewal.

The best countermeasure is to control steel shell deformation so the material of the shell was checked. Usually, the material of the shell was SS400, but in order to reduce the creep deformation, we chose a material that has creep resistance. The deformation behavior of the new shell material is shown in Fig.11. Compared with the former material, the deformation after one campaign is small, and there is little deformation progress after several campaigns. Therefore, we decided to use creep resistant steel in the case of shell renewal.

4. Improved results and the subject of future problems

As a result of above-mentioned actions, the campaign life of the lower vessel returned to the original level as shown in Fig.12, and the wear of the problem parts was decreased and sudden shut down by trouble has reduced.

However, these countermeasures are based on the assumption that the wear of the throat is caused by the stress on the throat brick, therefore the stress mechanism of the lower vessel must be analyzed quantitatively

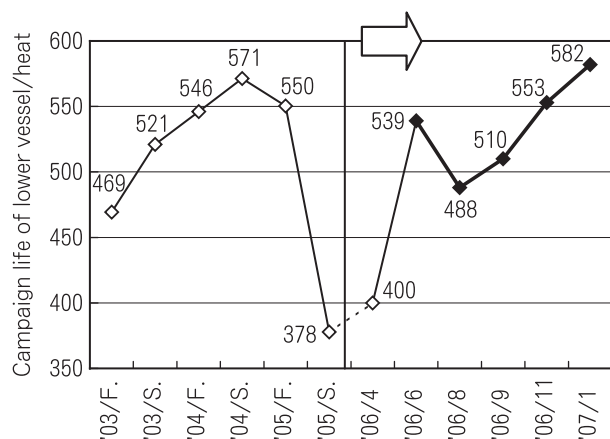


Fig.12 Change in campaign life of lower vessel at No.1RH.

炉内温度が最も低くなった時期にピークを示した。また、環流管れんがと槽底れんがの変形挙動も確認され、これらの結果から、構造体としての変位、変形が大きな応力に効いていると考えられる。さらに有効な対策を取るためには、いずれ応力発生メカニズムの検討が必要になるであろう。

5. まとめ

No. 3 RHの稼働に伴い操業状況が大きく変化し、同時に、No. 1 RH下部槽寿命が低下した。これに対して、RH用耐火物、補修頻度、槽底れんが材質、膨張代、槽底鉄皮変形の管理に関する対策が速やかに取られた。これらの改善により、問題部分の損傷が減り、トラブルによる突発停炉を低減することができた。

to estimate the propriety of these measures and to take adequate permanent actions. Now, stress analysis of the lower vessel is in progress around the throat bricks. The properties of both steel shell and bricks according to temperature change were taken into account for calculation. In this analysis, large stress appeared on the cracked position confirmed in an used brick, and the peak stress was observed when the temperature in the vessel was the lowest. Also the deformation behavior of the throat brick and the bottom brick was confirmed. These results suggest that displacement and deformation of brick lining structure are strongly related to stress. In order to take more effective countermeasures, the stress mechanism must be analyzed further in the future.

5. Summary

After the start of No.3RH operation, the service conditions have greatly changed, and the campaign life of the lower vessel decreased in No.1RH. Countermeasures were quickly taken to improve the RH refractories, repairing frequency, bottom brick material and expansion allowances, and the deformation of the bottom shell was controlled. With these improvements, wear of the problem parts decreased and sudden shut down of the vessel by trouble has been reduced.

References

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