

混鉄車に適用したECONOSライニングの熱収支

Heat Balance of “ECONOS” Low Thermal Conductivity Carbon Containing Brick Lining Applied for Torpedo Ladle

内 田 茂 樹*
Shigeki UCHIDA

Abstract

Heat-transfer analysis was conducted in order to study the heat balance in the torpedo ladle. More than 40% of liquid pig iron heat consumed when being transported by the torpedo ladle is absorbed and stored in the wear lining. Reducing the quantity of heat absorbed and stored in the wear lining is important. ECONOS bricks, which our company developed, were found to be effective for reducing the quantity of heat lost, which is strongly correlated with controlling temperature drop of liquid pig iron. On the other hand, insulation bricks which were applied as the safety lining were directly effective for reducing the quantity of heat radiated and lost from the shell. They were indirectly effective in reducing the temperature drop of the liquid pig iron. In order to most effectively reduce the drop in temperature of liquid pig iron, it is important that the ECONOS lining is combined with an insulation safety lining with optimally designed properties and proportions. Present analysis techniques are helpful for optimizing such designs.

1. はじめに

当社では、「環境にやさしい耐火物」を各種開発している。その一つである“ECONOSシリーズ”は耐用性を低下させることなく低熱伝導性を実現した炭素含有耐火物である。その特性により、溶湯温度低下抑制、鉄皮温度上昇抑制に効果を発揮している。ECONOSシリーズは、各所にて使用され好評を得ている^{1)~3)}。

一方、ECONOSシリーズの効果を定量的に明らかにする試みは、実機テスト、伝熱解析の両面から行われている^{4), 5)}。例えば、鍋のライニングを変えたときの鉄皮温度、鍋内溶湯の温度を検討することによりその効果、特徴を得ている。

本報ではECONOSシリーズおよび断熱材を配材した混鉄車を対象にした非定常伝熱解析により、搬送中に失われる溶湯熱量がどこにどの程度消費されるかを定量的に調べ、その効果、特長を

1. Introduction

We have developed many kinds of environment friendly refractory products. One of them, the ECONOS series, is carbon containing refractory products series, with low thermal conductivity without decreased ordinary service life. This characteristic is useful in controlling liquid iron temperature drop and shell temperature rise. ECONOS series products have been giving good performance in many furnaces^{1)~3)}.

Two methods have been tried to verify the effectiveness of ECONOS series products quantitatively. One is a trial test at an actual furnace and the other is heat-transfer analysis^{4), 5)}. For example, the effects and features of various types of ladle linings were examined in connection with shell and liquid iron temperatures.

In the present study, heat-transfer analysis was conducted on torpedo ladle models, for

*技術研究所 試験センター長 工学博士 Dr. Eng., Manager, Testing & Evaluation Center, Research Center

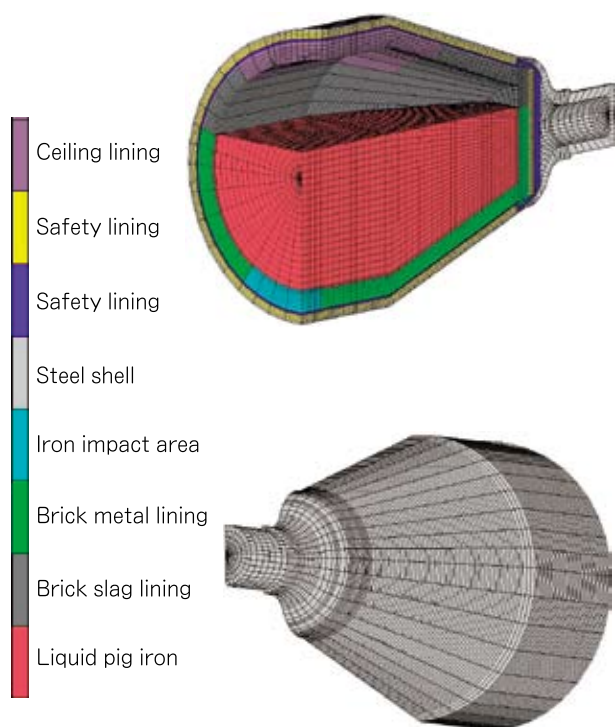


Fig. 1 Quarter section 3D-model for calculation, used because of the symmetry of the whole ladle.

明らかにした。

2. 解析用モデルと計算条件

Fig. 1に示すように、対称性を利用した3次元の1/4分割モデルを用いた。

本研究では、ウェアにECONOS系レンガを用いた場合のライニングの特徴を明らかにするために、通常配材、パーマに断熱材を用いた配材についても検討した。

ECONOS系レンガは、メタルライン、スラグライン、湯あたり部に適用した。通常レンガの熱伝導率が $17\sim 20[\text{W}/\text{m}\cdot\text{K}]$ に対して、ECONOS系レンガは約45%低い $10\sim 11[\text{W}/\text{m}\cdot\text{K}]$ であるが、密度、比熱のデータは、通常レンガとECONOS系レンガとではほぼ同じである。また、パーマ断熱材配材では、熱伝導率 $0.7[\text{W}/\text{m}\cdot\text{K}]$ の断熱材を用いた。

境界条件は実機を想定して設定した。すなわち、レンガ施工後の初期昇熱時に、炉内を室温から所定温度まで昇熱し、その温度で保持した。その後、 1510°C の溶銑を受け、滞留→出湯→空炉→受銑のサイクルを繰り返す計算を行った。

which the ECONOS series products and the insulation bricks were applied. In order to show the merits and validity of ECONOS series products, this paper describes the quantity of liquid pig iron heat lost and where it is transferred when being transported by a torpedo ladle.

2. Calculation Models and Conditions

As shown in Fig. 1, quarter section 3-D models were constructed for calculation, because of the symmetry of the whole ladle model.

In order to define the merits and effectiveness of the following three different lining configurations, ECONOS lining which consists of ECONOS wear bricks, a conventional lining and an insulation safety lining which consists of insulation safety bricks, investigation were carried out.

ECONOS bricks were applied for the metal, slag and impact area wear linings. The thermal conductivity of conventional wear bricks was $17\sim 20[\text{W}/\text{m}\cdot\text{K}]$ and that of ECONOS bricks was $10\sim 11[\text{W}/\text{m}\cdot\text{K}]$ which was about 45% lower than the conventional one. However, the data for the mass density and specific heat of the ECONOS bricks was approximately the same as those of the conventional. On the other hand, the thermal conductivity of the insulation bricks which were applied for the insulation safety lining was $0.7[\text{W}/\text{m}\cdot\text{K}]$.

The boundary conditions for calculation were set up on the assumption that an actual ladle was operated as follows. Namely, after refractory lining installation, the ladle was preheated from R.T. to the temperature appointed and was kept at the temperature before starting the operation. Then the ladle which was charged first with liquid pig iron at 1510°C was operated in cycles of transporting→discharging→waiting→charging.

3. Results and Discussion

The results are shown in Figs. 2-5 and Table 1.

- (1) The stationary temperature of the shell and liquid pig iron are illustrated for the 3rd to 4th heating cycle, as shown in Figs. 2 and 4. The analysis was done at the stationary temperature as follows.
- (2) Shell temperature was highest in the middle of the cone shell, as shown in Fig. 3.
- (3) Shell temperatures at the ECONOS

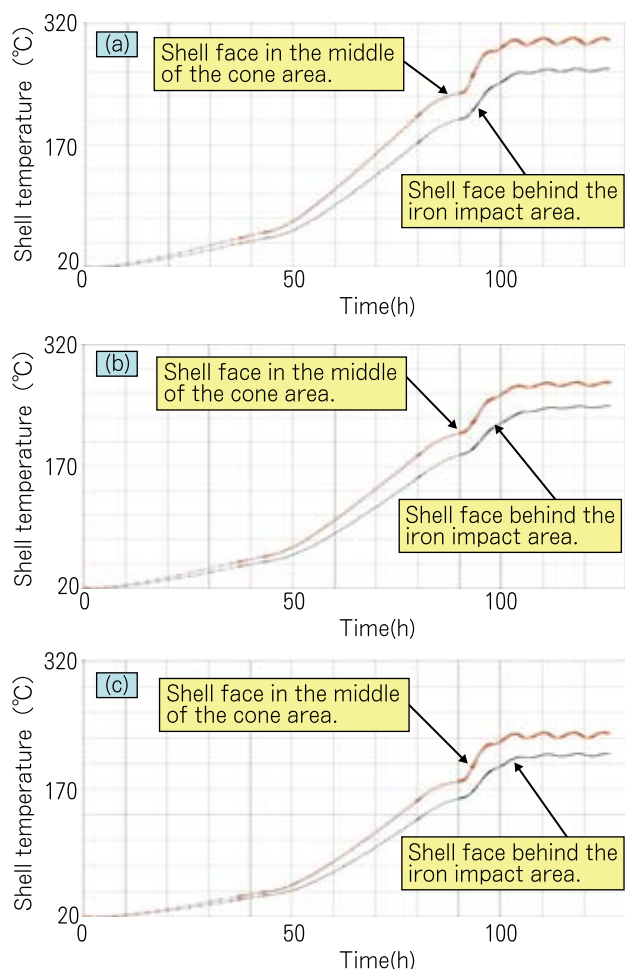


Fig. 2 Shell temperature for conventional lining (a), ECONOS lining (b) and insulation safety lining (c).

3. 結果と考察

結果をFig. 2-5, Table 1に示す。

- (1) 鉄皮温度、溶銑の平均温度とも3～4サイクル程度でほぼ安定した温度状態になっている (Fig. 2, 4)。以降では、この安定した状態で検討した。
- (2) 鉄皮温度は、絞り部中央で最も高くなった (Fig. 3)。
- (3) ECONOS系配材の鉄皮温度は通常配材よりも約25℃低く、パーマ断熱材配材では約60℃低かった。パーマ配材の鉄皮温度上昇抑制効果が大きかった。(Table 1)
- (4) 安定時の溶銑の ΔT (溶銑温度低下量 = 受銑時溶湯温度から出湯時温度を差し引いた値) は、通常配材で77℃, ECONOS系配材で69℃, パーマ断熱材配材で73℃であり、ECONOS系

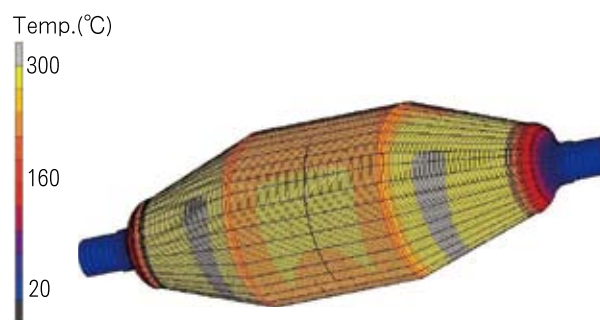


Fig. 3 Shell temperature distribution for the conventional lining during operation.

lining and the insulation safety lining were respectively 25℃ and 60℃ lower than that at the conventional. The insulation safety lining had a great effect on reducing the shell temperature, as shown in Table 1.

- (4) At the stationary temperature, ΔT was obtained by subtracting the value for liquid pig iron temperature at discharging from that at charging. ΔT was 77℃ for the conventional lining, 69℃ for the ECONOS lining and 73℃ for the insulation safety lining. The ECONOS lining had a great effect on reducing ΔT , as shown in Fig. 4.
- (5) If each lining performance is evaluated by only shell temperature, it might be concluded that the insulation safety lining is superior. However, if it is evaluated by ΔT which is the amount of temperature drop of the liquid pig iron, it can be concluded that the ECONOS lining is superior.

As mentioned above and shown in Fig. 5, the ECONOS lining seems to have an effect on reducing the heat quantity absorbed and stored in the wear lining, although the insulation safety lining was effective in reducing the heat quantity radiated and lost from the shell. These features are quantitatively explained in following section.

4. Heat Balance on Quantity of Heat Lost from Liquid Pig Iron between Charging and Discharging

4. 1 Calculation of heat quantity

The heat quantity ΔQ_i which is lost from liquid pig iron between charging and discharging is calculated according to equation

①.

Table 1 Shell temperature at the iron impact and the cone areas

	Conventional lining		ECONOS lining		Insulation safety lining	
	The minimum temp. during 5th heat.	The maximum temp. during 5th heat.	The minimum temp. during 5th heat.	The maximum temp. during 5th heat.	The minimum temp. during 5th heat.	The maximum temp. during 5th heat.
Shell face at the iron impact area.	2 6 1 °C	2 6 4 °C	2 4 2 °C	2 4 4 °C	2 0 9 °C	2 1 1 °C
Shell face at the middle of the cone area.	2 9 4 °C	3 0 1 °C	2 6 9 °C	2 7 4 °C	2 3 0 °C	2 3 6 °C

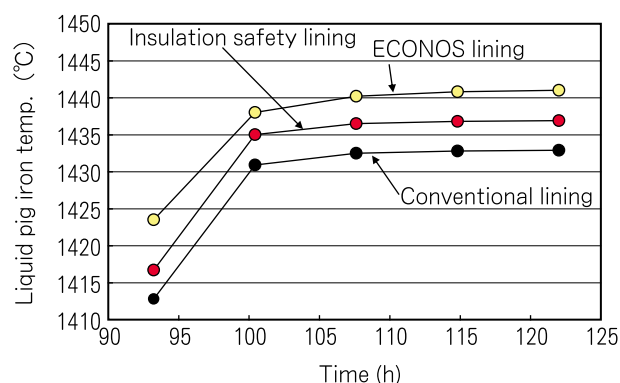


Fig. 4 Liquid pig iron temperature just before discharging at 1ch to 5ch.

配材の ΔT の低下を抑制する効果大きい。
(Fig. 4)

- (5) 鉄皮温度で評価するなら、パーマ断熱材配材が優位であるが、溶銑温度低下量の ΔT で評価するなら、ECONOS系配材が優位である。

以上の結果およびFig. 5より、ECONOS系配材は、通常配材に比べウェアライニングへの蓄熱抑制の効果を示唆している。一方、パーマ断熱材配材は主に鉄皮からの放熱量抑制に効果が推定される。これらの特徴を以下で定量的に調べる。

4. 受銑から出湯までの溶銑熱量の収支計算

4.1 熱量の算出方法

受銑から出湯までに溶銑から失われるエネルギー ΔQ_I は、①式のように分配される。

$$\Delta Q_I = \Delta Q_S + \Delta Q_W + \Delta Q_O \cdots \cdots \cdots \text{①}$$

ここで、 ΔQ_S : 鉄皮からの放熱量、 ΔQ_W : ウェ

$$\Delta Q_I = \Delta Q_S + \Delta Q_W + \Delta Q_O \cdots \cdots \cdots \text{①}$$

Where, ΔQ_S is the heat quantity radiated and lost through the shell, ΔQ_W is the heat quantity absorbed and stored in the wear lining and ΔQ_O is the heat quantity radiated and lost through the other areas such as the ladle mouth and absorbed and stored in areas such as the safety lining. Those were calculated according to following equations.

$$\Delta Q_I = C_I \times W_I \times \Delta T \cdots \cdots \cdots \text{②}$$

$$\Delta Q_S = H_S \times (T_S - T_O) \times S \times t \cdots \cdots \cdots \text{③}$$

$$\Delta Q_W = C_W \times W_W \times \Delta T_W \cdots \cdots \cdots \text{④}$$

$$\Delta Q_O = \Delta Q_I - (\Delta Q_S + \Delta Q_W) \cdots \cdots \cdots \text{⑤}$$

Where, C_I is the specific heat of liquid pig iron, W_I is the weight of liquid pig iron in the ladle, H_S is the overall heat transfer coefficient between the shell and air, T_S is the average temperature of the shell, T_O is the atmosphere temperature, S is the area of the shell surface, t is the length of transportation time in the torpedo ladle, C_W is the specific heat of the wear bricks, W_W is the total weight of the wear bricks used for the ladle and ΔT_W is the average temperature of the wear bricks which is elevated to between charging and discharging.

4.2 Calculation results

The heat quantity was calculated by quarter section 3-D models which were constructed for calculation because of the symmetry of the whole ladle. The total heat quantity for a torpedo ladle was estimated by four times of value calculation. The results are shown in Table 2 and Fig. 6.

In the case of any of the three linings, the

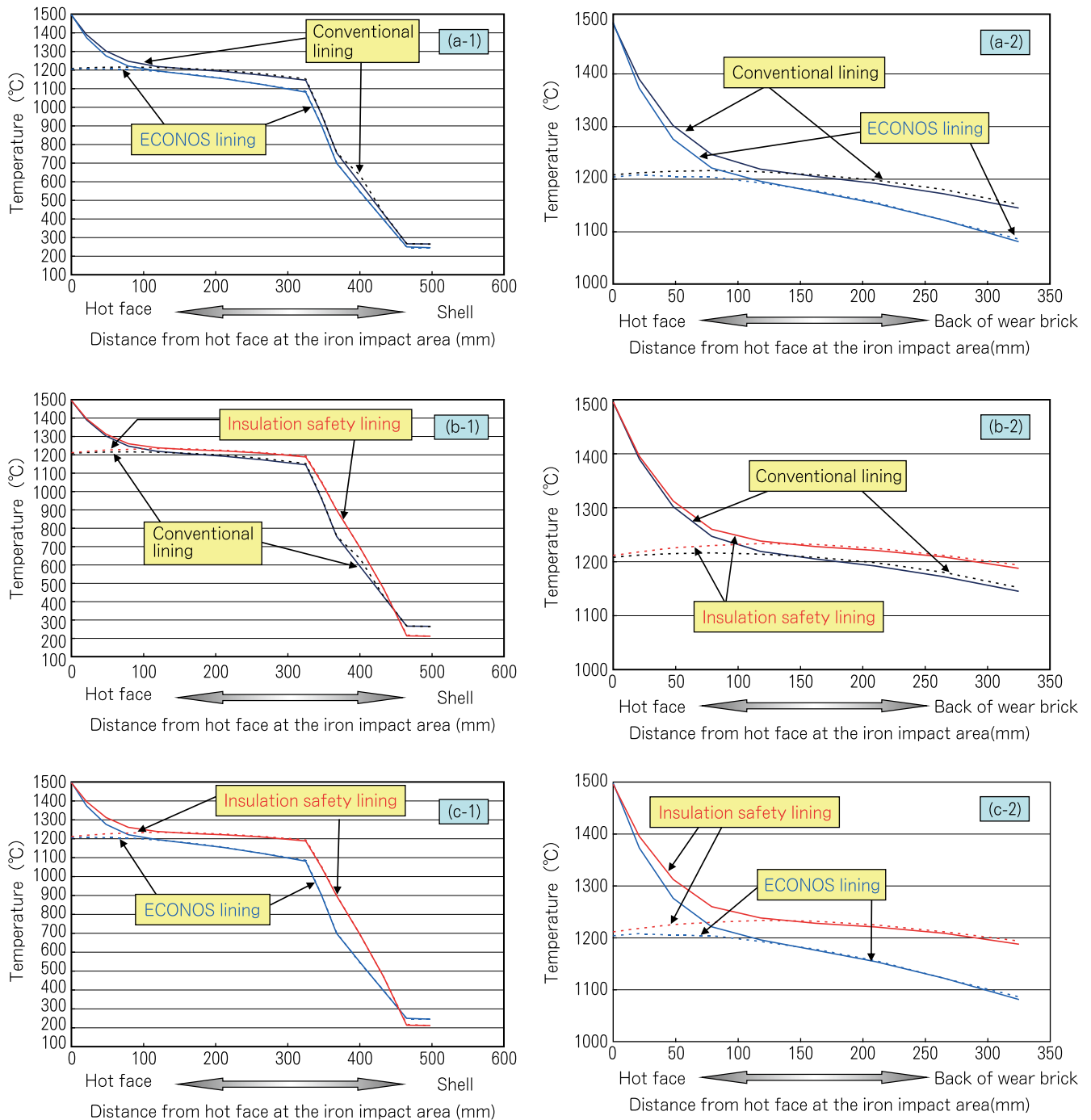


Fig. 5 Temperature gradient between hot face and cold face of wear bricks at the iron impact area. (Solid lines show results just before charging at the 5th heat. Broken lines show results just before discharging liquid pig iron at the 5th heat.)

アーライニング内に蓄熱される熱量， ΔQ_0 ：その他の放熱，蓄熱量（受鉄口からの放熱，パーマライニングへの蓄熱等が想定される。）である。さらに、これらの量は以下のようにして算出した。

heat quantity which was absorbed and stored in the wear lining was the largest and over 40% of the total heat quantity lost from liquid pig iron. The heat quantity radiated and lost through the shell was 30 plus percent. Other influencing factors were around 20%. Accordingly, the

$$\Delta Q_I = C_I \times W_I \times \Delta T \cdots \cdots \cdots \textcircled{2}$$

$$\Delta Q_S = H_S \times (T_S - T_O) \times S \times t \cdots \cdots \cdots \textcircled{3}$$

$$\Delta Q_W = C_W \times W_W \times \Delta T_W \cdots \cdots \cdots \textcircled{4}$$

$$\Delta Q_O = \Delta Q_I - (\Delta Q_S + \Delta Q_W) \cdots \cdots \cdots \textcircled{5}$$

ここで、 C_I ：溶銑の比熱、 W_I ：受銑量、 H_S ：鉄皮と外気との総括熱伝達率、 T_S ：鉄皮平均温度、 T_O ：外気温、 S ：鉄皮表面積、 t ：滞留時間、 C_W ：ウェアレンガの比熱、 W_W ：ウェアレンガの使用量、 ΔT_W ：ウェアレンガの平均温度上昇分である。

4. 2 計算結果

本解析は1/4モデルに対して行なっているので、算出量を4倍した値が混銑車全体の熱量になる。結果をTable 2とFig. 6に示す。

いずれの場合も、ウェアライニングへの蓄熱がもっとも多く、全体の40%以上であり、次いで、鉄皮からの放熱量が30数%、その他は20%程度であった。したがって、ウェアライニングへの蓄熱量を減らす対策が効果的と考えられる。

ECONOS系配材またはパーマ断熱材配材の効果の詳細を知るために、Table 2の算出熱量から以下の計算を行った（ここで、各記号の意味はTable 2を参照）。得られた結果をFig. 7に示す。

$$\Delta Q_{I(e-c)} \equiv \Delta Q_{Ie} - \Delta Q_{Ic} \cdots \cdots \cdots \textcircled{6}$$

$$\Delta Q_{I(p-c)} \equiv \Delta Q_{Ip} - \Delta Q_{Ic} \cdots \cdots \cdots \textcircled{7}$$

$$\Delta Q_{S(e-c)} \equiv \Delta Q_{Se} - \Delta Q_{Sc} \cdots \cdots \cdots \textcircled{8}$$

$$\Delta Q_{S(p-c)} \equiv \Delta Q_{Sp} - \Delta Q_{Sc} \cdots \cdots \cdots \textcircled{9}$$

$$\Delta Q_{W(e-c)} \equiv \Delta Q_{We} - \Delta Q_{Wc} \cdots \cdots \cdots \textcircled{10}$$

effective countermeasure is to decrease the heat quantity absorbed and stored in the wear lining.

In order to understand the effect of the ECONOS lining and the insulation safety lining in detail, the following ⑥－⑬ calculations were conducted using the heat quantity values in Table 2. The meaning of the following symbols is shown in Table 2. The results are shown in Fig. 7.

$$\Delta Q_{I(e-c)} \equiv \Delta Q_{Ie} - \Delta Q_{Ic} \cdots \cdots \cdots \textcircled{6}$$

$$\Delta Q_{I(p-c)} \equiv \Delta Q_{Ip} - \Delta Q_{Ic} \cdots \cdots \cdots \textcircled{7}$$

$$\Delta Q_{S(e-c)} \equiv \Delta Q_{Se} - \Delta Q_{Sc} \cdots \cdots \cdots \textcircled{8}$$

$$\Delta Q_{S(p-c)} \equiv \Delta Q_{Sp} - \Delta Q_{Sc} \cdots \cdots \cdots \textcircled{9}$$

$$\Delta Q_{W(e-c)} \equiv \Delta Q_{We} - \Delta Q_{Wc} \cdots \cdots \cdots \textcircled{10}$$

$$\Delta Q_{W(p-c)} \equiv \Delta Q_{Wp} - \Delta Q_{Wc} \cdots \cdots \cdots \textcircled{11}$$

$$\Delta Q_{O(e-c)} \equiv \Delta Q_{Oe} - \Delta Q_{Oc} \cdots \cdots \cdots \textcircled{12}$$

$$\Delta Q_{O(p-c)} \equiv \Delta Q_{Op} - \Delta Q_{Oc} \cdots \cdots \cdots \textcircled{13}$$

The ECONOS lining was better in reducing the quantity of heat lost from liquid pig iron than the insulation safety lining.

The ECONOS lining reduced not only directly the quantity of heat which was absorbed and stored in the wear lining but also indirectly the quantity of heat which was radiated and lost through the shell and stored in and radiated through the other areas.

On the other hand, insulation safety lining reduced the quantity of heat radiated and lost through the shell very well. However the quantity of heat which was absorbed and stored in the wear lining and was stored in and radiated

Table 2 Balance of heat quantity lost from liquid pig iron during torpedo transport

	Conventional lining		ECONOS lining		Insulation safety lining	
	Temp.[°C]	Heat[kWh]	Temp.[°C]	Heat[kWh]	Temp.[°C]	Heat[kWh]
Heat lost from liquid iron during torpedo transport	Decrease of $\Delta T=77^{\circ}\text{C}$	$\Delta Q_{Ie}=5,202$	Decrease of $\Delta T=69^{\circ}\text{C}$	$\Delta Q_{Ie}=4,662$	Decrease of $\Delta T=73^{\circ}\text{C}$	$\Delta Q_{Ie}=4,932$
Heat radiated and lost through the shell surface	Shell average temp. 248°C	$\Delta Q_{Sc}=1,928$ $\Delta Q_{Sc}/\Delta Q_{Ie}=37\%$	Shell average temp. 228°C	$\Delta Q_{Sc}=1,759$ $\Delta Q_{Sc}/\Delta Q_{Ie}=38\%$	Shell average temp. 202°C	$\Delta Q_{Sp}=1,539$ $\Delta Q_{Sp}/\Delta Q_{Ip}=31\%$
Heat absorbed and stored in wear lining	Increase of 87.5°C	$\Delta Q_{Wc}=2,206$ $\Delta Q_{Wc}/\Delta Q_{Ie}=42\%$	Increase of 77°C	$\Delta Q_{We}=1,944$ $\Delta Q_{We}/\Delta Q_{Ie}=42\%$	Increase of 90.6°C	$\Delta Q_{Wp}=2,284$ $\Delta Q_{Wp}/\Delta Q_{Ip}=46\%$
Other heat lost		$\Delta Q_{Oc}=1,068$ $\Delta Q_{Oc}/\Delta Q_{Ie}=21\%$		$\Delta Q_{Oe}=959$ $\Delta Q_{Oe}/\Delta Q_{Ie}=20\%$		$\Delta Q_{Op}=1,109$ $\Delta Q_{Op}/\Delta Q_{Ip}=23\%$

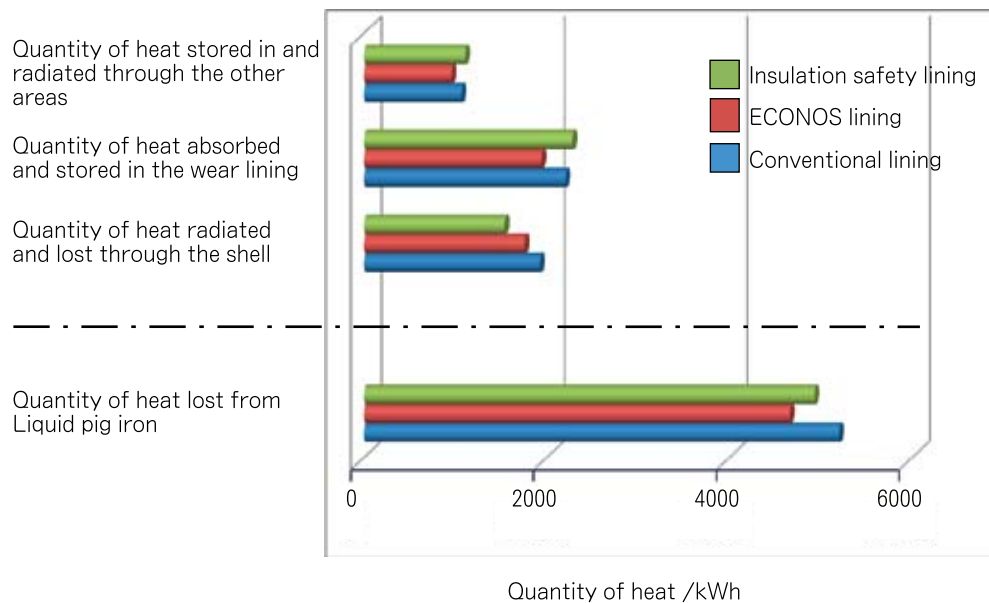


Fig. 6 Balance of heat quantity lost from liquid pig iron during torpedo transport.

$$\Delta Q_{W(p-c)} \equiv \Delta Q_{Wp} - \Delta Q_{Wc} \dots\dots\dots ⑪$$

$$\Delta Q_{O(e-c)} \equiv \Delta Q_{Oe} - \Delta Q_{Oc} \dots\dots\dots ⑫$$

$$\Delta Q_{O(p-c)} \equiv \Delta Q_{Op} - \Delta Q_{Oc} \dots\dots\dots ⑬$$

ECONOS系配材の方がパーマ断熱材配材よりも溶銑熱量のロスを小さくできている。

ECONOS系配材では、ウェアライニングへの蓄熱量を直接的に抑制するだけでなく、間接的に鉄皮からの放熱、その他における蓄熱・放熱を抑制している。

一方、パーマ断熱材配材では、鉄皮からの放熱抑制はよく効いているが、逆に、ウェアライニングへの蓄熱、その他は増しており、これらに対してマイナスに作用している。

5. まとめ

混銑車を対象にして、通常配材、ECONOS系配材、パーマ断熱材配材に関して、溶銑が滞留しているときの熱収支を検討した。

- ・ 混銑車内に滞留している間に消費される溶銑熱量の40%以上がウェアライニングに蓄熱される。ウェアライニングへの蓄熱量抑制が重要な対策であることがわかった。
- ・ ECONOS系配材はウェアライニングへの蓄熱量抑制に効果を発揮するだけでなく、間接的に鉄皮からの放熱、その他における蓄熱・放熱を抑制している。

through the other areas increased. So, that lining had a bad effect on the wear lining and the other areas.

5. Summary

Heat balance during liquid pig iron transport was studied using calculation models for torpedo ladles which were configured with a conventional lining, ECONOS lining or insulation safety lining.

- ・ More than 40% of the quantity of liquid pig iron heat consumed when being transported by torpedo ladle was absorbed and stored in the wear lining. Reducing the heat quantity absorbed and stored in the wear lining is important.
- ・ The ECONOS lining not only directly reduced the heat quantity which was absorbed and stored in wear lining but also indirectly reduced the quantity of heat which was radiated and lost through the shell and stored in and radiated through the other areas.
- ・ The insulation safety lining reduced the quantity of heat radiated and lost through the shell. However the quantity of heat which was absorbed and stored in the wear lining and stored in and radiated through the other areas increased. It had a bad effect on the wear lining and the other areas.
- ・ Insulation safety lining was able to reduce

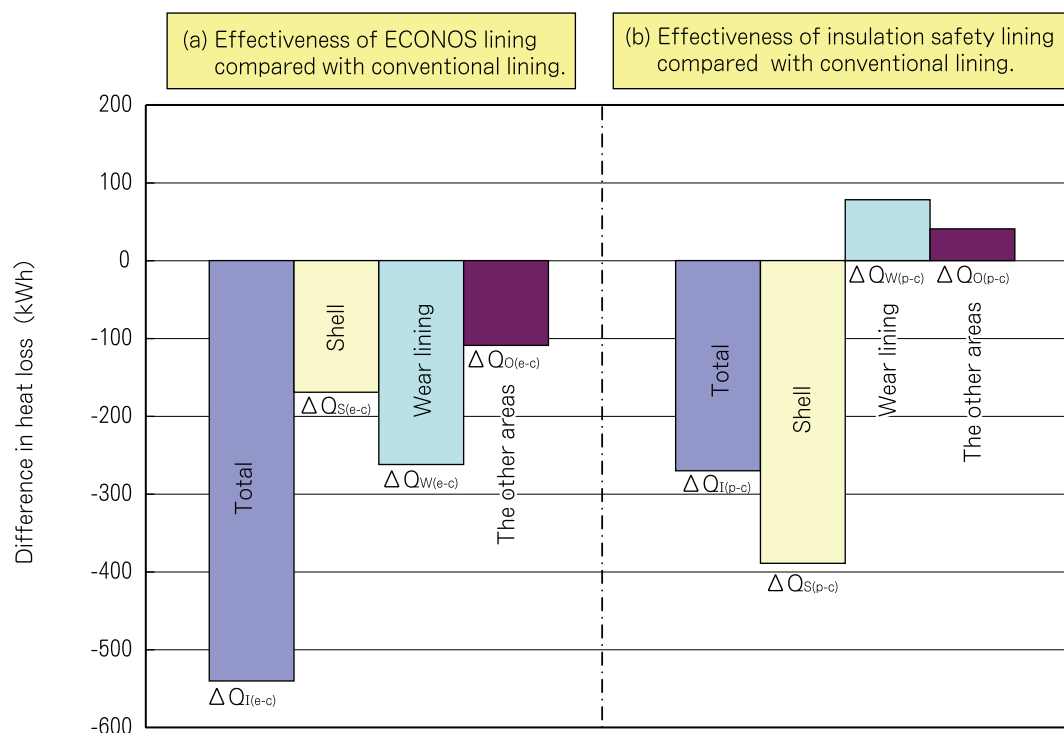


Fig. 7 Difference in heat loss which was calculated by subtracting the heat loss of the conventional lining from that of the ECONOS lining (a) and that of the insulation safety lining (b). Meaning of symbols is shown in text.

- ・一方、パーマ断熱材配材は鉄皮からの放熱量抑制に効果を発揮するが、逆に、ウェアライニング、その他への蓄熱・放熱量を増やすマイナスの働きをしている。
- ・パーマ断熱材配材は鉄皮温度を低く抑えることができる。これが間接的に溶銑温度低下抑制に結びついている。
- ・鉄皮温度を調べても溶銑温度低下抑制を評価することは必ずしもできないことがわかった。
- ・溶銑温度低下をもっとも効果的に抑制するには、ECONOSとパーマ断熱材の特性と寸法比率を最適化して組み合わせることが重要である。
- ・本解析法はそのような設計の最適化に役に立っている。

the shell temperature. That was indirectly connected with reducing the drop in temperature of the liquid pig iron.

- ・ It was suggested that the shell temperature measurement data could not always permit an accurate estimation of whether the drop in temperature of liquid pig iron was reduced or not.
- ・ In order to most effectively reduce the drop in temperature of liquid pig iron, it is important that the ECONOS lining is combined with an insulation safety lining with optimally designed properties and proportions.
- ・ Present analysis techniques are helpful for optimizing such designs.

References

- 1) O. Nomura, Y. Hoshiyama and A. Torigoe : Shinagawa Technical Report, **42**, 39 (1999)
- 2) H. Shikama and M. Yoshida : Shinagawa Technical Report, **48**, 97 (2005)
- 3) H. Tada, H. Tomiya and M. Yoshida : Shinagawa Technical Report, **50**, 75 (2007)
- 4) S. Uchida and O. Nomura : Taikabutsu, **52**, 640 (2000)
- 5) T. Okimura, K. Sakakidani, M. Hagiwara, S. Uchida, Y. Hoshiyama and A. Torigoe : Shinagawa Technical Report, **44**, 1 (2001)