

SHINAGAWA TECHNICAL REPORT

CGLメッキ炉用耐火物の紹介

Introduction to Highly Durable Refractories
Applied for Metal Pot in CGL

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要 旨

CGL設備のメッキ炉は溶融する金属の種類によって操業条件は様々であり、各種条件に応じた耐火物を開発している。特に操業条件の厳しいガルバリウムメッキ炉ではインダクター部の耐用が課題であり、主な停炉原因はメタル中の金属Alとの反応による湯道の詰まりと熱スポーリングによって生じた亀裂からの湯漏れである。メタルとの反応性と耐スポーリング性の改善したインダクターブロック(CST-A6125, CST-S530)を使用した結果、良好な使用結果が得られた。

Abstract

Since the operational condition of the CGL metal pot varies according to type of zinc-based alloy to be galvanized on the steel strip, refractory products best suited for each operational condition have been developed. In the CGL operation for Galvalume steel strip, in which, due to the severest operational conditions, incidents caused by clogging of the molten metal circulating channel with reactant derived from the Al component in zinc-based alloy or by metal leakage from initiated cracks occasionally take place, high metal pot durability, especially its inductor block, is required. By applying newly developed castable refractories (CST-A6125, CST-S530), which are characterized by minimized reactivity with the Al component in zinc-based metal as well as by improved spalling resistance, to the metal pot inductor block, satisfactory performance has been achieved.

1. 緒言

連続溶融亜鉛メッキライン(Continuous Galvanizing Line : CGL)とは、溶融した亜鉛を主とする金属の中に薄鋼板を連続的に浸漬することで表面に薄膜を被覆(メッキ)してメッキ鋼板を製造する設備である。CGLにてメッキに用いられる金属はFig.1に示す通り様々あり、純粋な亜鉛、ガルバリウム(重量比Zn : Al=45 : 55)、ガルタイト(重量比Zn : Al=95 : 5)、その他に亜鉛やアルミニウム以外の金属を含有する独自の合金のメッキ商品を製造するケースもある。それらの溶融金属の種類やメーカーによって炉の構造や操業条件は多岐に渡っており、Table 1に示すように耐火物に必要な特性も異なるため、これまでに多様な

1. Introduction

CGL (Continuous Galvanizing Line) is a mass-production facility for galvanized steel strip products in which steel strips are continuously dipped in zinc-based molten alloy to obtain a finishing thin antirust coating layer on the steel strip surface. As indicated in Fig. 1, various types of zinc-based alloys, such as pure zinc, Galvalume composed of 45 % zinc and 55 % aluminum in weight ratio, Galtite composed of 95 % zinc and 5 % aluminum in weight ratio or other unique zinc-based alloys which is composed of other kinds of metals are used at the appropriate operational temperature. Since, depending on the type of zinc-based alloy or other production factors, the structure of the zinc-based alloy metal

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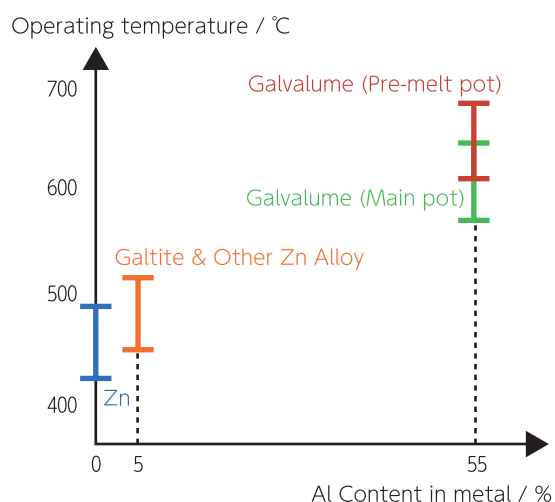


Fig. 1 Types of zinc-based alloy and operating temperatures in CGL operation.

Table 1 Significant requirements of refractories applied to CGL metal pot

	Zn pot	Galtite or Galvalume metal pot
Spalling resistance	++	+++
Reactivity with Al component	+	+++
Infiltration resistance to Zn	++	+

pot (hereinafter simply referred to metal pot) and its operational conditions are widely varied, as per Table 1, refractory requirements used for the CGL metal pot are differentiated. In response to significance of CGL metal pot refractory requirements, various kinds of development or improvements have been conducted. The new improvements and performance of the refractories in practical CGL metal pot operation are reviewed in this article.

2. Outline of CGL Metal Pot

As an example, the structure of a metal pot in a CGL facility for Galvalume steel strip is schematically illustrated in Fig. 2, along with typically used refractories. The zinc-based alloy metal pot used in the CGL is one type of channel induction furnace, which is characterized by a combination of a channel as a flowing passage of molten metal and inductor as heating device. A schema of an inductor in a CGL metal pot is illustrated in Fig. 3. During operation, molten metal circulating in the channel is heated up as well as being driven to flow in the direction indicated with arrows by a low frequency electric inductor coil set in the central hollow space so as to maintain metal temperature evenly. In CGL facilities for Galvalume steel strip in which zinc-aluminum alloy is coated on the steel strip surface, a pre-melt pot where metal ingot is melted with appropriate compositions is additionally equipped along with a metal pot for steel strip surface coating. Because there is no necessity for adjustment of molten metal composition, no pre-melt pot is required in the CGL facility for zinc galvanized steel strip products.

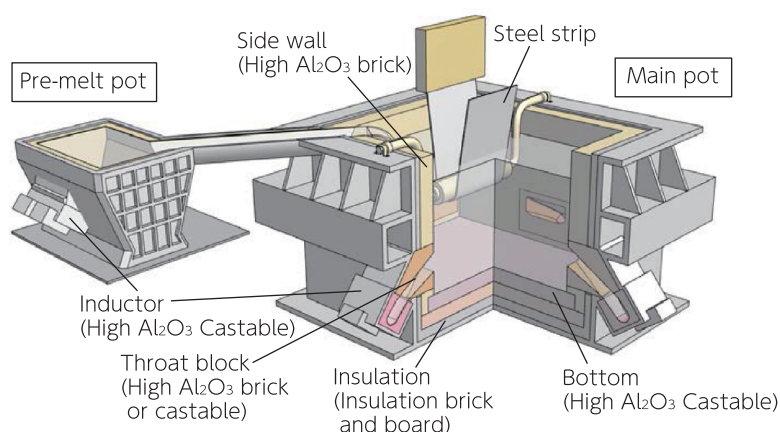


Fig. 2 Schematic drawing of metal pot in CGL for Galvalume steel strip.

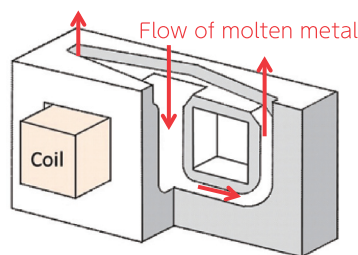


Fig. 3 Schema of inductor in CGL metal pot (Double channel type).

製品の開発と改善がなされている。本稿ではCGL用耐火物の特徴や改善結果について報告する。

2. メッキ炉の概要

Fig.2にCGL設備の例としてガルバリウムメッキ炉の構造と耐火物の配材例を示す。CGLで用いられるメッキ炉は溝型誘導炉と呼ばれる炉の一種であり、炉の側面にメタルが通る溝とインダクターと呼ばれる加熱装置が設置されることが特徴である。Fig.3にインダクターの模式図を示す。メッキ炉の操業中はインダクターの中央の穴にセットされた低周波コイルによって湯道内のメタルが誘導加熱されると同時に図中の矢印の方向に流れが生じることによって炉内のメタルが攪拌され、温度が均一に維持される。また、ガルバリウムメッキ炉では亜鉛とアルミニウムの合金をメッキするため、インゴットの溶解と成分調整を実施するプリメルトポットと、薄鋼板を浸漬してメッキを施すメインポットがセットとなっている。他方で、亜鉛メッキ炉の場合は成分調整の必要が無い場合プリメルトポットは付属しない。

3. メッキ炉用耐火物

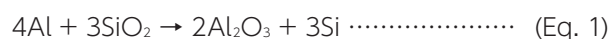
Table 2にメッキ炉に使用される代表的な耐火物の品質を示す。メッキ炉の操業温度は製鋼炉などと比べると大幅に低いために耐熱性能はほとんど必要がない。しかし、メッキ炉で熔融する金属の内、亜鉛は他の金属と比べて表面張力が極めて低く、耐火物の微細な気孔や亀裂へ容易に浸潤しやすい性質を持つため、れんがであればMLM-45L、キャストブルであればCST-JAMCOのような緻密質のアルミナ系材質が亜鉛メッキ炉で使用される。

一方で、アルミニウムに対しては、下記(Eq.1)の反応式にて耐火物中の SiO_2 が還元されると同時にアルミニウムが Al_2O_3 質の反応物あるいは付着物として成長し、構造スポーリングを生じたり付着物や剥離片がインダクターの内

3. Refractories Applied to Metal Pot

The physical and chemical properties of refractories applied to the CGL metal pot are summarized in Table 2, along with their major characteristics. Since the operating temperature of the CGL metal pot is much lower than that of steel refining furnaces, significant heat resistance is not required. Since the surface tension of molten zinc, the major metal component for galvanized molten metal, is markedly lower than that of other metallic components, zinc component tends to infiltrate easily into tiny pores or micro cracks in the refractory body. For this reason, highly densified alumina refractory products, such as MLM-45L brick or CST-JAMCO castable refractory, are usually applied to the CGL metal pot for zinc galvanized steel strip products.

The aluminum component in zinc-based molten alloy could reduce SiO_2 component contained in refractory as per equation (1), resulting in generation of Al_2O_3 as reactant or adhesive substance. Since generated Al_2O_3 component would induce structural spalling in refractory body or metal circulating channel could be clogged with adhesive substance or peeled-off pieces of Al_2O_3 reactants, suspension of operation caused by refractory incidents or channel clogging is a concern.



As preventive measure for such incidents, ALT-85R brick or CST-A6125 or CST-S530 castable refractories, all of which are characterized by ultra-low SiO_2 content and low reactivity with metallic aluminum, are applied for CGL metal pot for aluminum containing zinc alloy galvanized steel strip product, such as Galvalume steel strip.

4. Improvement of CGL Metal Pot Refractories and Performance in Practical Operation

Since the inductor shown in Fig.3 is the most important and critical component affecting stable operation of the CGL metal pot, incidents would immediately cause suspension of CGL operation. Precast castable refractory block (hereinafter referred to as "inductor block") is commonly used as the refractory body for the metal circulating channel. Improvement research on CGL metal pot refractories have been carried out mainly on castable refractories applied as inductor block. Improvement works on castable refractory for inductor block is main subject of this article.

Table 2 Physical and chemical properties and major characteristics of refractories applied to CGL metal pot

Material		Brick		Castable		
Brand		MLM-45L	ALT-85R	CST-JAMCO	CST-A6125	CST-S530
Apparent porosity	/ %	13.5	20.0	11.5※	12.0※	11.0※
Bulk density	/ g·cm ⁻³	2.40	2.80	2.99※	3.18※	2.70※
Cold crushing strength	/ MPa	98.0	78.4	56.9※	132.5※	50.9※
Permanent liner change	/ %	—	—	-0.09※	0.00※	-0.01※
Thermal expansion	/ % at 1000℃	0.50	0.60	0.72	0.76	0.35
Thermal conductivity	/ W/m·K at 800℃	1.7	1.9	2.1	3.9	9.1
Chemical Composition / mass%	Al ₂ O ₃	46	84	84	90	11
	SiO ₂	—	—	10	5	4
	Fe ₂ O ₃	1.2	1.5	—	—	—
	SiC	—	—	—	—	78
Charac- teristics	Spalling resistance	★★★★	★★★★	★★★☆	★★★☆	★★★★
	Metal(Al) reaction resistance	★★☆☆	★★★★	★★☆☆	★★★★	★★★★
	Infiltration(Zn) resistance	★★★★	★★★☆	★★★★	★★★★	★★★★
Applicable metal	Zinc	★★★★	★★★☆	★★★★	★★★☆	★★★★
	Galtite	★★☆☆	★★★★	★★☆☆	★★★★	★★★★
	Galvalume	★★☆☆	★★★★	★★☆☆	★★★★	★★★★

※After heating at 110℃-24h

★Suitability

部に詰まって操業不能に陥るリスクがある。



このようなトラブルの対策として、ガルバリウム等のアルミニウムを含むメッキ炉用耐火物では低SiO₂質でアルミニウムとの反応性が低いALT-85RやCST-A6125, CST-S530等の材質が主に使用されている。

4. メッキ炉用キャストブルの改善と実機適用例

メッキ炉において最も停炉トラブルの原因になりやすく、炉全体の安定操業に影響を及ぼす部位はインダクター部である。インダクターの中で金属が流れるチャンネルを構成する耐火材としてはプレキャストブロックが採用されることが多く、過去のCGL向けの耐火物開発の多くはインダクター用プレキャストブロック(以下、インダクターブロックと呼ぶ)の改善を中心になされているので、以下に改善事例を紹介する。

4. 1 アルミニウム反応性の改善

一般的な耐火物においてガルバリウムに含まれる金属Alとの反応を抑制する方法の一つとしては、より高Al₂O₃かつ低SiO₂質の材質を適用する方法がある。しかし、Al₂O₃値を高くすると耐スポーリング性がより悪化する傾向となるためインダクターの亀裂から湯漏れトラブルを生じるリスクが増え、必ずしも耐用の改善に繋がらない。そこで、新たな方法として特殊添加物(ノンウェット材)を添加する

4. 1 Improvement for minimizing reactivity with Al component

Generally applied measure to suppress the reaction between refractories and the Al component contained in zinc-based molten alloy, such as Galvalume, is to adopt high Al₂O₃ refractory material with minimized SiO₂ content. When a refractory is composed solely of high Al₂O₃ material, its spalling resistance tends to be lowered along with increased risk of metal leakage from cracks initiated in the inductor block. That is, application of high Al₂O₃ refractory material does not always result in improved durability. Hence, special additive with low wettability was admixed to newly developed castable refractory CST-A6125, so as to prevent the refractory surface from being wetted with molten metal in order to suppress the reaction with the Al component. For evaluating the effect of the special additive on reactivity with Al component, crucible specimen samples made of CST-A6125 and refractory brick with equivalent Al₂O₃ content, both in which metallic Al was packed, were heated at 1000℃ for 100 hours in an electric furnace. Cross sections of two specimen samples are comparatively shown in Fig.4. A dark colored reaction layer was generated on the inner surface of the crucible specimen sample made of refractory brick. While, no reaction layer is observed on the inner surface of the crucible specimen sample made of CST-A6125 castable refractory, and the solidified lump of

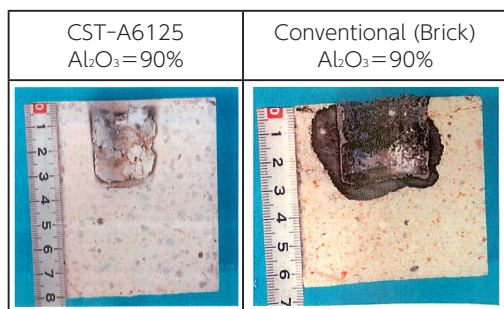


Fig. 4 Comparison of reactivity with Aluminum between two types of castable refractories after heating at 1000°C for 100 hours.

ことで耐火物とメタルとの濡れを抑制し反応性を改善した CST-A6125を開発した。Fig.4にるつぼ状に加工した耐火物と金属Alを電気炉にて1000°Cで100hキープした反応試験の結果を示す。 Al_2O_3 含有量がCST-A6125と同等のれんがはメタルとの反応層が黒色に変化しているのに対して、CST-A6125は反応層が生成しておらずメタルと耐火物を素手で容易に剥がすことができる。

CST-A6125および従来の高 Al_2O_3 材質を同一のガルバリウム用インダクターブロックとして使用した後の切断写真をFig.5に示す。両者を比較すると、従来材質は湯道の周囲に黒色の反応層が生じているのに対してCST-A6125はほとんど観察されなくなっており、詰まりが原因となる停炉トラブルはCST-A6125の採用以降は大幅に減少した。しかし、CST-A6125の主な停炉原因は湯道を中心に生じた亀裂からのメタル漏れであり、ブロックの耐スポーリング性はCST-A6125と従来材質は同等であった。そのため、亀裂からのメタル漏れトラブルを解消するための更なる対策品としてCST-S530を開発した¹⁾。

4. 2 耐スポーリング性の改善

CST-S530はCST-A6125と同じ添加物(ノンウェット

metallic Al could be easily removed by hand.

Cut faces of inductor blocks made of CST-A6125 and conventional high Al_2O_3 castable refractory, both of which were used in CGL operation for Galvalume steel strip, are comparatively shown in Fig. 5. A dark colored reaction layer is observable on the metal flow channel surface of the conventional inductor block associated with radially running internal cracks. However, no reaction layer is observed on the metal flowing channel surface of CST-A6125 inductor block. In practical operation, incidents caused by channel clogging are markedly reduced by adoption of CST-A6125 castable refractory for the inductor block. However, incidents caused by metal leakage from initiated cracks in inductor block made of CST-A6125, with spalling resistance equivalent to that of conventional material, still take place occasionally. As described in the following sub-section, CST-S530, with better spalling resistance was developed¹⁾ to eliminate metal leakage incidents from initiated cracks.

4. 2 Improvement for better spalling resistance

Similar to CST-A6125, a special additive with low wettability was admixed to CST-S530 castable refractory. It is characterized by low reactivity with Al component in zinc-based alloy associated with reduced clogging incidents. Since, as shown in Table 2, SiC is applied as a main aggregate material, CST-S530 castable refractory is also characterized by lower thermal expansion rate and higher thermal conductivity than those of conventional high Al_2O_3 castable refractories. These are more advantageous characteristics for improved spalling resistance.

Temperature and stress distribution maps of inductor block, which were calculated by FEM simulation on 1/4 cut model of an inductor block under the steady state heat transmission of which metal flow channel temperature is kept at 850°C, are comparatively shown in Fig. 6. It was affirmed that

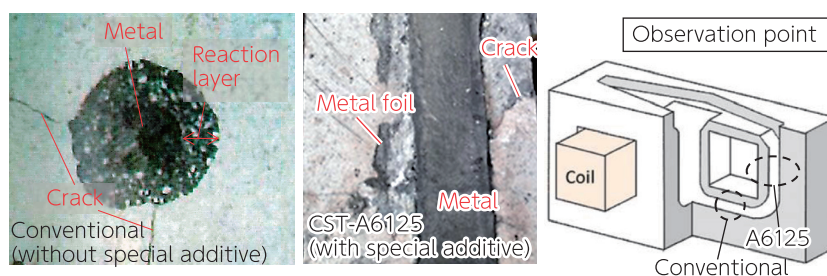


Fig. 5 Cut faces of conventional material and CST-A6125 inductor block used in CGL operation for Galvalume steel strip.

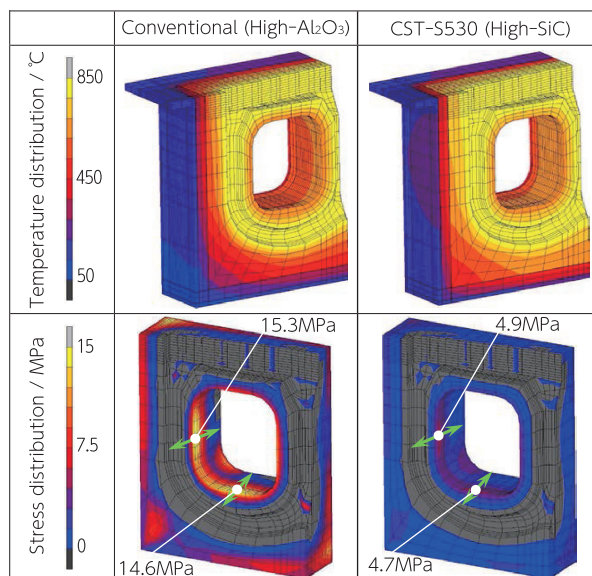


Fig. 6 Temperature and stress distribution maps of conventional material and CST-S530 inductor block calculated by FEM simulation.

材)を使用した効果により金属Alとの反応や詰まりを生じにくい特徴を持つ。更に主骨材をSiCとしたことで、Table 2に示す通り従来の高 Al_2O_3 材質より熱膨張率が低く、熱伝導係数が高いため、耐熱スポーリング性に非常に優れる特徴がある。

Fig.6はインダクターブロックを縦横にカットした1/4サイズモデルを用いて、湯道の温度が850℃の定常状態と仮定した場合のブロック内の温度分布と応力分布をFEMによってシミュレーションした結果である。操業中にインダクターブロックに亀裂と湯漏れが生じる場合は、特に湯道と中央の穴の間の箇所に生じる亀裂が停炉の主因となるケースが多く、この結果でも同箇所に高い引っ張り応力が発生することが確認されているため、このシミュレーション結果は実機で生じる現象と整合していると考えられる。材質間の発生応力を比較すると、CST-S530に生じている応力は従来の高 Al_2O_3 材質と比べて少なく、およそ1/3程度に改善されている。

CST-S530および高 Al_2O_3 質の従来品を同一の亜鉛メッキ炉用インダクターブロックとしてほぼ同期間使用した後の切断写真をFig.7に示す。両者共に稼働面でのメタルとの反応はどちらも軽微であり差は無いが、従来材質はブロックの内部に無数の亀裂が生じて亀裂内にメタルが浸透している様子が確認できる。その一方でCST-S530は目視で観察できる範囲で亀裂の発生は全く無く、大幅に損傷が

in almost all metal leakage incidents cracks initiated at the middle position of the wall between central hollow space for induction coil setting and metal flowing channel. Since the highest tensile stress is generated at the identical position of the inductor block in FEM simulative calculation, it is inferred that simulative calculation results conform to phenomenon observed in practical metal pot operation. When comparing calculated tensile stress values, the generated tensile stress in CST-S530 inductor block was roughly one-third of that in Conventional high- Al_2O_3 inductor block, meaning lowered crack sensibility of CST-S530.

The cut faces of inductor blocks made of CST-S530 and conventional high- Al_2O_3 material, both of which have been used in CGL operation for zinc galvanized steel strip for a certain period, are comparatively shown in Fig.7. No reaction layer is observed on the metal flow channel surface of either inductor block. While many cracks, which are accompanied with metal penetration, are observable in the conventional inductor block, no visually observable cracks were generated in CST-S530 inductor block. That is, the degree of refractory damage has been significantly reduced in CST-S530 inductor block.

Because of lowered reactivity with Al component in zinc-based molten alloy as well as improved spalling resistance, CST-S530 can be applied not only for inductor block but also as relining material for metal



Fig. 7 Cut faces of conventional material and CST-S530 inductor block used in CGL operation for zinc galvanized steel strip.

改善されている。

このように、CST-S530はアルミニウムとの反応を生じ難いだけでなく耐スポーリング性にも優れる特徴があるため、様々な亜鉛含有金属のメッキ炉においてインダクターブロックとしての用途以外に側壁内張り用材質としても使用されるなど適用範囲が徐々に広がっており、好評を博している。

5. まとめ

CGL設備メッキ炉用材質の特徴とこれまでの開発経緯を紹介した。CGLの中でも操業条件が厳しく操業のネックとなるガルバリウム用インダクターでは湯道の詰まりと亀裂からの湯漏れが従来の課題であり、その改善品として開発したCST-A6125やCST-S530の採用例が増えている。その一方で、比較的操業条件の軽い亜鉛用インダクターの材質としてはCST-JAMCOが現在も各所で使用されて安定した耐用を示しており、各メーカーの操業条件や解決したい課題に応じてれんがや断熱構造も含めた最適な材質を提案することが可能である。

pot wall in CGL facilities for Galvalume, Galtite and zinc galvanized steel strips with favorable reputations.

5. Conclusion

Characteristics of refractories applied to the CGL metal pot were reviewed along with typical durability improvement work. For the Galvalume steel strip metal pot in the CGL facility, where, due to the severest operational conditions because of the nature of zinc-based alloy, incidents caused by metal flowing channel clogging and/or metal leakage from initiated cracks have been problems, application of newly developed CST-A6125 or CST-S530 castable refractory has gradually increased. For the metal pot in the zinc galvanized steel strip CGL facility in which the operational conditions are not so severe, conventional castable refractory, CST-JAMCO, is broadly applied with stable performance at various CGL facilities. In accordance with operational conditions as well as troublesome issues to be solved CGL operation, our company is ready to provide suggestions for appropriate refractory materials as well as thermal insulation measures for the metal pot.

Reference

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