Improvement of Steel Casting Ladles
～Extension of Service Life by Application of Unfired Alumina-Magnesia Brick, ALTIMA～

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Abstract

This article describes the history of steel ladle refractory improvement implemented in Akimoku steel Co., Ltd. in association with Ceratechno Co., Ltd. While newly developed unfired alumina-magnesia brick ALTIMA showed a much smaller wear rate, it wasn't enough to extend its service life. Thanks to another several technological developments such as inhibition of steel skull adhesion, improvement of well block durability and suitable application of troweling repair, its service life improved from 100 heats to 180 heats, resulting in 47 % reduction in the overall specific cost of steel ladle refractories.

1. Introduction

Akimoku steel smelts steel in a 10 T-Heroult electric arc furnace and the molten steel is tapped to a 8 T or 7 T steel ladle, followed by steel casting. In 2016, we reported a countermeasures for improving excavation damage of the hearth ramming material of the electric arc furnace that had been caused by the increase in the stainless products. Since then, it has maintained a stable condition without large repairs until now.

On the other hand, in the case of the steel ladle, the average number of heats between full lining repairs was unstable at around 100 heats due to the diversification of the type of smelted steel. It has been a problem in terms of cost and furnace construction work load. This report describes a result of ladle refractory improvement that achieved stable service life and extended life by a factor of 1.8, resulting in a reduction of the overall refractory material cost by 47 %.

2. Ladle Repair Patterns

2. 1 Conventional lining and repair patterns

Conventionally, two types of bricks had been applied as the ladle's wear lining, one was zircon brick for the side wall and the bottom impact area and the other was high alumina brick for the general part. Table 1 shows a conventional repair pattern. The big repair, which replaces all bricks subsequent to dismantling of entire zone, was carried out every 100 heats while the small repair, which exchanges bottom impact area bricks and well block, was

Table 1 Conventional repair pattern

100 heats pattern (Conventional)	0 → 25	50	75	100
	25 heats	25 heats	25 heats	25 heats
〔Repair method〕				
• Bottom brick replacement	○	○	○	＜Dismantle＞
• Well block replacement	○	○	○	
• Impact area replacement	–	○	–	

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Table 2　Typical properties of ALTIMA

	Alumina-Magnesia brick ALTIMA
Chemical composition / mass% Al_2O_3 MgO	 88 7
Apparent porosity / % Bulk density / - CCS / MPa	10.0 3.40 63

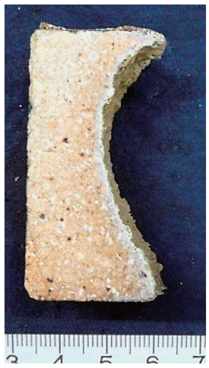
done every 25 heats and the medium repair, in which bricks of wall impact area are exchanged, was done every 50 heats.

3.　Investigations of Suitable Materials for Steel Ladle

The price of zircon brick is unstable since it is strongly influenced by supply and demand. This is because of the uneven distribution of the natural resources. On the other hand, alumina-magnesia castables are used for steel ladles of many integrated steel mills because the raw material supply is relatively stable and the castables exhibit high durability. However, castables require mixers and dryers capable of precise temperature control. Hence, unfired alumina-magnesia brick (ALTIMA) is a candidate as an alternative. ALTIMA is a brick with the equivalent characteristics of alumina-magnesia castable, and therefore no casting facility is required. Table 2 shows the typical properties of ALTIMA.

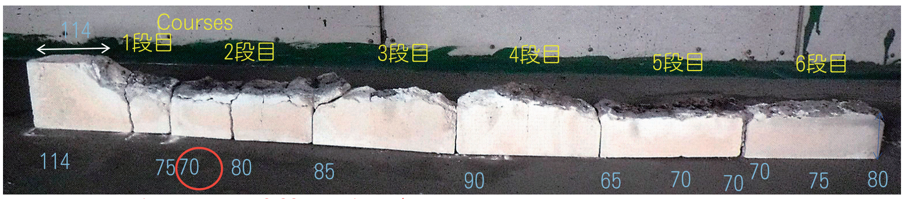
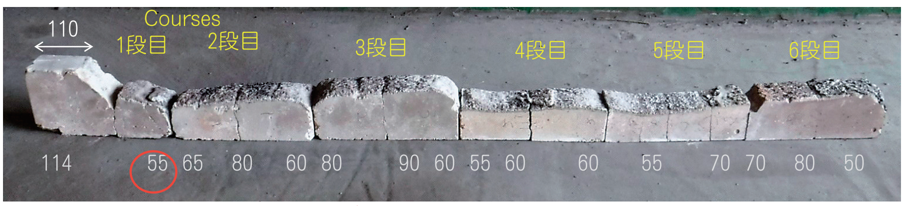
Table 3 shows comparison of the corrosion resistance of zircon brick and ALTIMA brick. The evaluation was carried out by rotating crucible method for 60 minutes at a temperature of 1650 ℃ using a slag (C/S=1.6), which had been obtained from an actual steel ladle just after receival of stainless steel tapped from an electric arc furnace. As shown in the cross-sectional photograph after the test, ALTIMA brick showed excellent corrosion resistance compared to zircon brick. The relative corrosion amounts were 15 for ALTIMA and 100 for zircon. Therefore, it was judged that ALTIMA brick was applicable to a commercial steel ladle and an industrial trial began.

Table 3　Corrosion resistance

	Zircon brick	ALTIMA
Cut section after corrosion test		
Corrosion / mm	9.2	1.1
Index / -	100	15

Rotation crucible method
Temp.－Time : 1650 ℃ － 60 min
Slag : Actual slag for stainless steel refining.
Obtained from ladle of AKIMOKU Steel just after tapping.
Exchanged every hour during the test.

Table 4　Residual thickness of side wall after use

	Side wall course 1 to 6
Tested ALTIMA [109 heats] 1-3 : 50 heats 4-6 : 109 heats	 Impact area 0.88 mm•heat^{-1}
Conventional Zircon brick [75 heats] 1-3 : 25 heats 4-6 : 75 heats	 Impact area 2.36 mm•heat^{-1}

4. Results of ALTIMA Brick Trial

4. 1 Sidewall wear

Table 4 shows the results of the sidewall application trial of ALTIMA brick compared to zircon brick. The number of heats for ALTIMA brick was 50 heats for layer 1 to 3, which corresponds to the impact are, and 109 heats for layer 4 to 6, while those for zircon brick were 25 heats for layer 1 to 3 and 75 heats for layer 4 to 6. For both cases, the thinnest residual thicknesses were observed for layer 1 and 2 to where the tapped molten steel impacts severely.

With respect to the wear rate, the ALTIMA showed 0.88 mm/heat, which is much smaller compared to the 2.36 mm/heat that was observed for zircon brick. Thus, considerable extension of ladle service life is expectable. In order to achieve it, improvements in durability of the well block and impact area are necessary. Taking the original thickness of the side wall (114 mm) into account and assuming an effective residual thickness of 30 mm, target service lives of the well block, impact area and general wall were set as 45 heats, 90 heats and 180 heats, respectively. While theoretical calculation predicts 34.8 mm for the residual thickness of the wall impact area, fluctuation of wear rate according to changes in operating condition should be taken into consideration. Thus, combined application of troweling repair was assumed. The target repair pattern for this test is shown in Table 5.

4. 2 Adherence of molten steel skull to bottom

As a trial, ALTIMA bricks were used for the full lining. As a result, serious steel skull adhesion to the bottom surface took place so that it became necessary to remove

Table 5 Target repair pattern

100 heats (Conventional)	0 → 25 → 50 → 75 → 100 25 heats, 25 heats, 25 heats, 25 heats
180 heats (Trial)	0 → 45 → 90 → 135 → 180 45 heats, 45 heats, 45 heats, 45 heats
Repair methods	At 45: Bottom brick replacement, Well block replacement, Troweling repair for wall impact area At 90: Bottom brick replacement, Well block replacement, Wall impact area brick replacement At 135: Bottom brick replacement, Well block replacement, Troweling repair for wall impact area

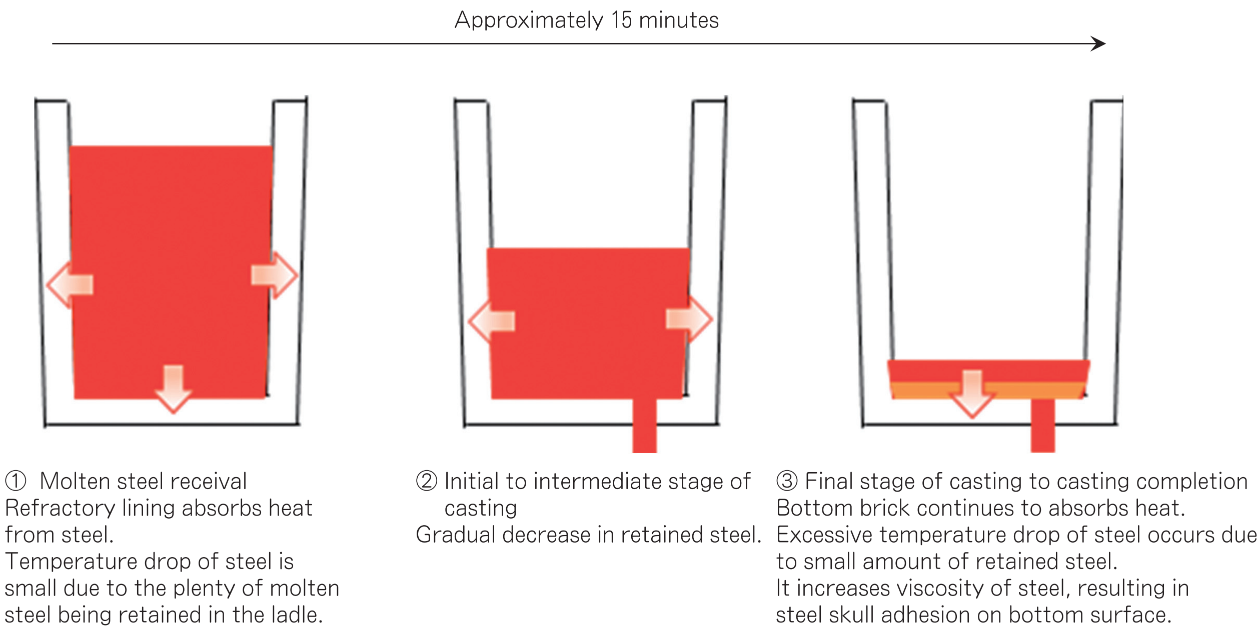


Fig. 1 Hypothesis for steel skull adhesion on bottom.

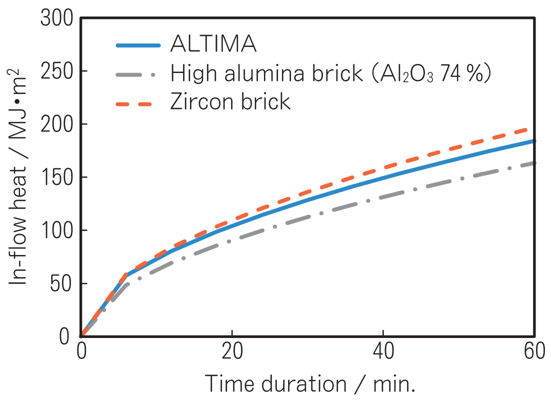
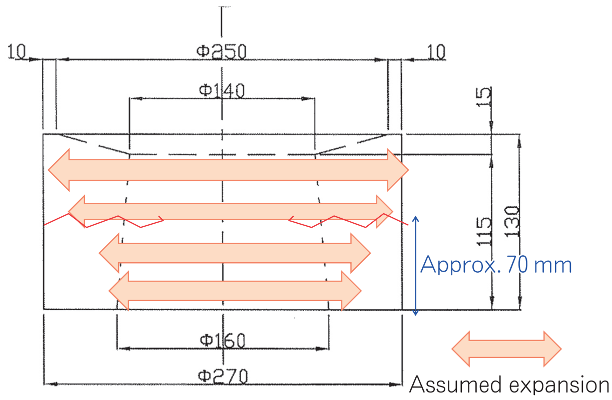


Fig. 2 Calculated changes in in-flow heat of ladle.

Table 6 Typical properties of high alumina bricks

	LBA-8 Al_2O_3 81%	Conventional Al_2O_3 74%
Modulus of rupture / MPa	15.2	9.6
Cold crushing strength / MPa	97.0	57.8
Apparent porosity / %	20	23.3
Bulk density / -	2.75	2.56
Apparent density / -	3.43	3.33

Table 7 Corrosion resistance of high alumina brick for bottom



it by oxygen flushing during the slag discharging-maintenance stage after casting completion. This is considered attributable to the difference in in-flow heat. Although the in-flow heat of the ALTIMA brick-installed ladle is almost equivalent to that of the zircon brick-installed ladle, it is smaller than that of the high alumina brick-installed ladle. Therefore, excessive temperature drop of molten steel occurs for the ALITIMA full-installed ladle at the final stage of casting when the amount of retained molten steel becomes smaller, resulting in an increase in molten steel viscosity. The drainage difficulty due to high viscosity caused the steel adhesion. Figures 1 and 2 show the hypothesized steel adhesion process and theoretical difference in in-flow heat of the ladle to which the materials were installed, respectively.

According to the hypothesis, high strength high alumina brick LBA-8 was used in the area of which traditional high alumina brick had been installed since its heat capacity is larger than that of ALTIMA. Figure

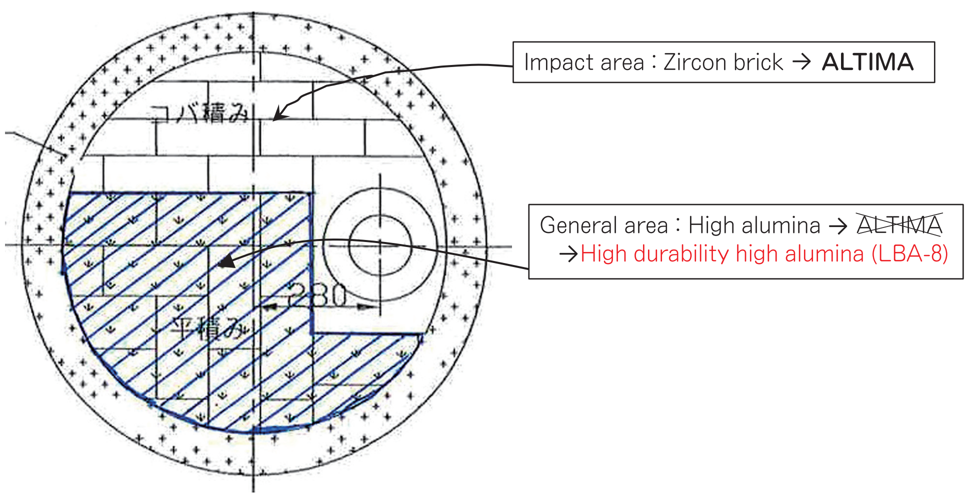
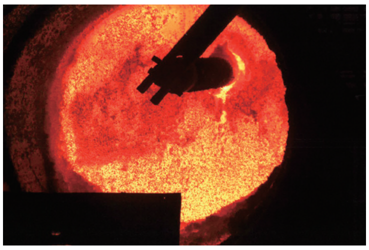
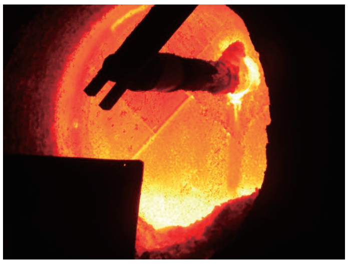
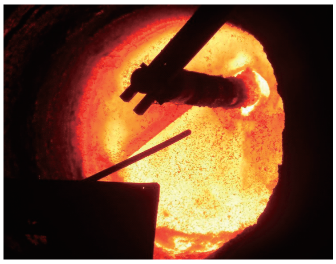


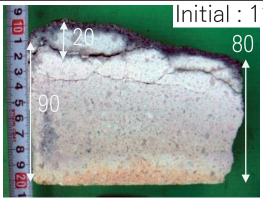
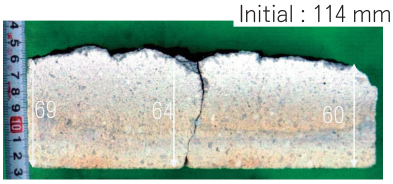
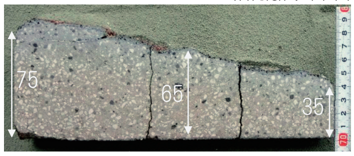
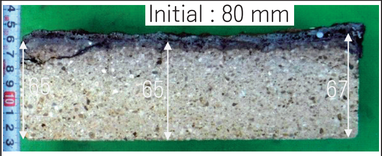
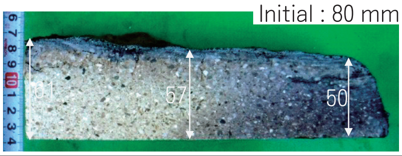
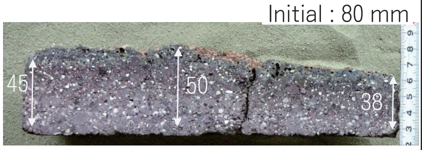
Fig. 3 Bottom brick lining.

Table 8 Steel skull adhesion configuration

Steel skull adhesion (Trial 1) (SiC-coated ALTIMA)	No adhesion (Conventional) (Zircon & High alumina brick)	Less adhesion (Trial 2) (ALTIMA & LBA-8)
		

Steel skull adhesion became smaller to acceptable level by application of ALTIMA & LBA-8 for ladle bottom.

Table 9 Residual thickness of bottom brick after 25 heats

	Trial 25 heats		Conventional 25 heats
	ALTIMA : Central area	ALTIMA : Peripheral area	Zircon brick
Impact area	Initial : 114 mm 	Initial : 114 mm 	Initial : 114 mm 
	LBA-8 : Opposite side to nozzle	LBA-8 : Opposite nozzle side	Conventional high alumina brick
General area	Initial : 80 mm 	Initial : 80 mm 	Initial : 80 mm 

3, Tables 6 and 7 show schematic illustrations of the bottom brick arrangement, typical properties of two high alumina bricks and result of corrosion resistance evaluation, respectively. This brick arrangement reduced the steel skull adhesion to the acceptable level as shown in Table 8.

4. 3 Bottom wear

Table 9 shows the cut surface of a bottom brick after 25 heats. Both ALTIMA and LBA-8 showed sufficient residual thickness in comparison with conventional zircon brick and high alumina brick. In this application, the residual thickness of ALTIMA brick-installed area around the well block was insufficient. The wear of this area is attributable to rapid wear of well block, 25 heats maximum. Hence, it was considered that improvement of well block durability would reduce the wear rate of the ALTIMA brick-installed area around the well block.

4. 4 Well block test results (1)

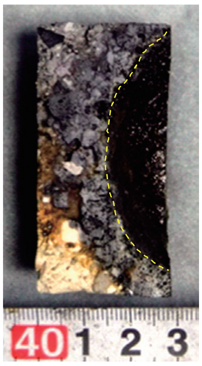
In order to extend the 25 heats service life of conventional high alumina well block, the effect of well block made of alumina-magnesia material AMP-8Y2 was evaluated. Tables 10 and 11 summarize the typical properties and corrosion resistance of well block, respectively.

As a result of commercial application, AMP-82Y showed horizontal cracking at a 70 mm height from the back end, which was at the middle range of its initial

Table 10 Typical properties of well brocks

		Alumina-Magnesia	High alumina
		AMP-8Y2	Conventional
Chemical composition / mass%	Al_2O_3 MgO SiO_2	92 6 	82.4 9.4
Apparent porosity / %		15.5	21.5
Bulk density / -		3.20	2.70
Cold crushing strength / MPa		60	41

Table 11　Corrosion resistance of well blocks

	Alumina-Magnesia AMP-8Y2	High alumina Conventional
Cut section after corrosion test		
Depth	5.4 mm	13.4 mm
Index	41	100

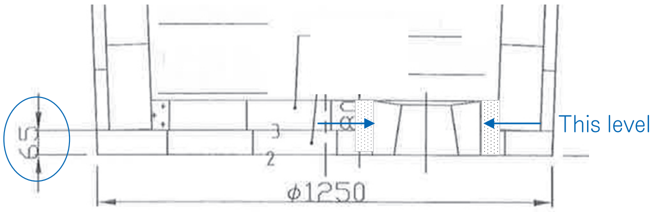
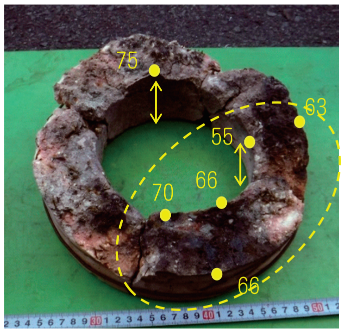


Fig. 4　Cracking position of well block.

thickness of 130 mm as shown in Table 12. As shown in Fig. 4, the cracking occurred at the interface level of the ALTIMA brick and permanent lining.

After the trial, the well block was retrieved and mineralogical compositions of upper and lower part from the crack were evaluated by X-ray diffraction method. Figure 5 shows the result. Although magnesia, which is indicated as “M”, was detected in the lower part, it disappeared,

Table 12　Situation of well block after 41 heats

	External view from shell	Upper side	Lower side
After 41 heats			

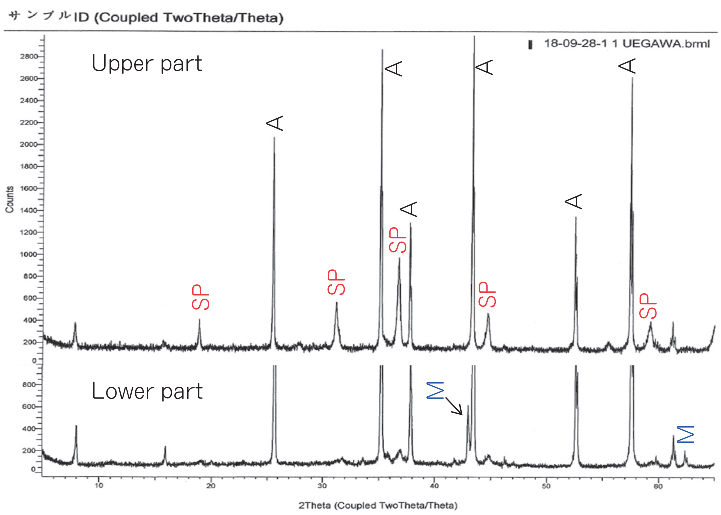


Fig. 5　XRD spectrum of well block after use.

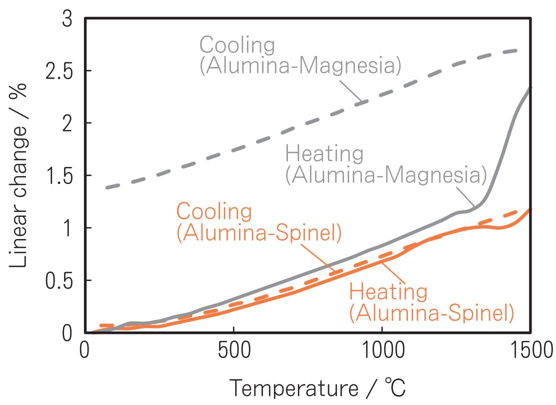


Fig. 6　Thermal expansion behaviors.

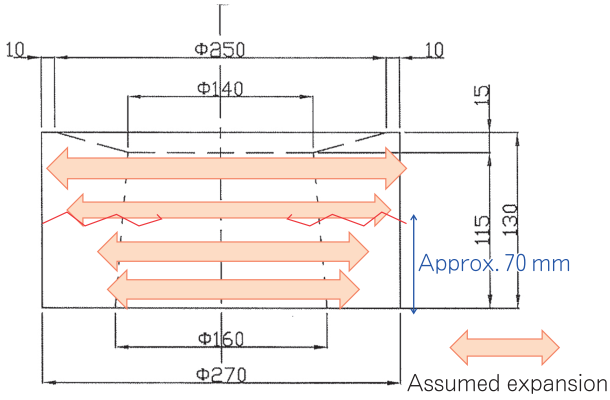


Fig. 7　Schematic illustration of expansion mismatch.

and spinel, which is indicated as “SP”, was detected in the upper part. As a result of the spinel forming reaction, alumina-magnesia material showed rapid expansion above 1200 ℃ as shown in Fig. 6.

$Al_2O_3 + MgO \rightarrow MgAl_2O_4$ (spinel)

From these facts, the cause of cracking is inferred as follows. Although rapid expansion according to the spinel formation reaction occurs in the upper side at which sufficient heat is provided from molten steel, the expansion of the lower side is smaller since no spinel formation is expected due to the lower temperature. This situation creates a volume expansion mismatch, resulting in cracking at the middle range of its lining. This configuration is schematically illustrated in Fig. 7.

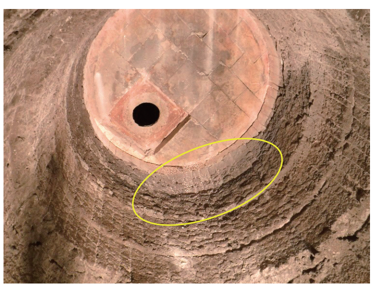
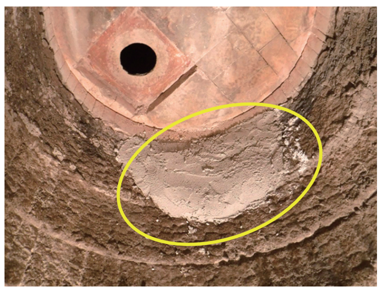
4. 5　Well block test results (2)

Therefore, in order to reduce the influence of expansion due to spinel forming reaction, a well block made of AMP-8Y2, which had been fired at over 1300 ℃ in advance, were tested. The result was that 44 heats were achieved without middle range cracking. Wall wear was the limiting factor at 44 heats. According to the investigation of the samples obtained from the well block after application, it was judged to be good and still usable. Hence, it was clarified that 45 heats was achievable.

4. 6　Troweling repair material test results

In order to repair local corrosion of the impact area, alumina-magnesia troweling material was evaluated as the material for intermediate repair, which is carried out between brick replacing repairs. Table 13 summarizes the test results. Troweling repair material SSC-AM340T is used as paste kneaded with water. As a result of the trial, good workability for installation, which resulted from easy adjustability of the paste softness by controlling the amount of water, as well as sufficient durability, that is, 7 to 8 heats without peeling-off. Accordingly, excellent adhesion during operation was confirmed.

Table 13　Trial result of troweling repair material

Impact area wear (50 heats)	Troweling repair	2 heats after repair (89 to 90 heats)
		
Local wear of impact side at course 1 to 2	20 kg of troweling repair	Troweling repair material sticks to ALTIMA firmly

4. 7 Results of trials for 45 heat cycle-repairs

Table 14 summarizes condition of the bricks after use. ALTIMA was used for the side wall and both ALTIMA and LBA-8 were used for bottom. They were 91 heats and 41 heats, respectively. According to the investigations of these samples, sufficient durability of these bricks was confirmed.

The fired well block made of alumina-magnesia AMP-8Y2 was used as trial for 45 heat cycle-repairs. For the well block, a small troweling repairs were applied. The results are shown in Table 15. While the repair had been carried out every 25 heats or less conventionally, the

Table 14 Investigation of the bricks after use

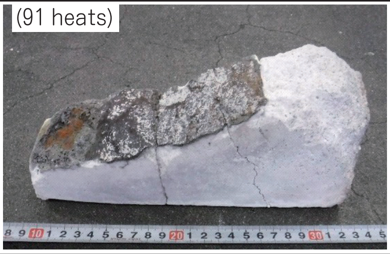
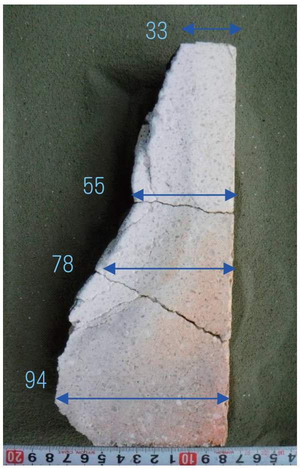
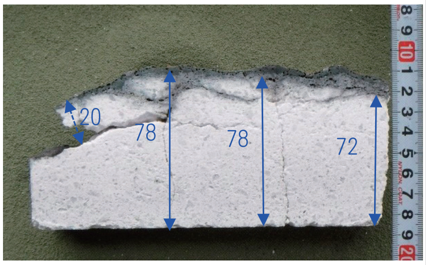
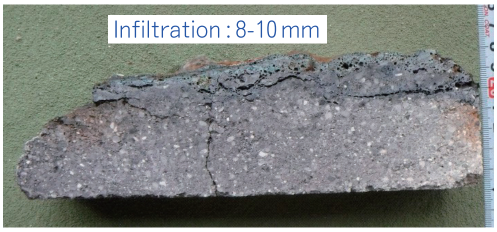
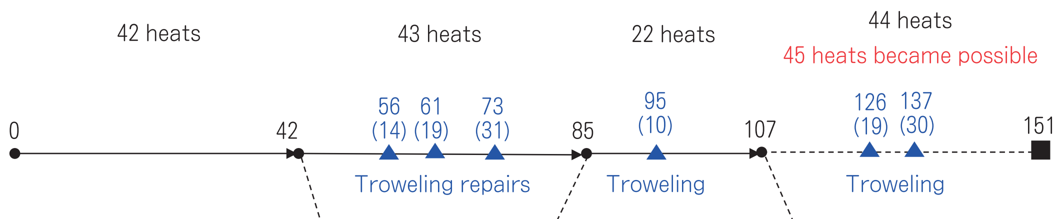
	ALTIMA for wall of impact area / course 1 (91 heats)	ALTIMA for bottom (41 heats)	LBA-8 for bottom (41 heats)
External appearance			
Cut section	 Initial thickness : 114 mm, Target heats: 90 heats The thinnest point (33 mm) covered by troweling material (30 to 40 mm). 3 troweling repairs after 50 heats.	 Initial thickness : 114 mm, Target heats : 50 heats Peeling-off occurs. Residual thickness (more than 70 mm) predicts target heats (45) achievement.	 Initial thickness : 80 mm, Target heats : 50 heats Peeling-off occurs. Residual thickness (more than 60 mm) predicts target heats (45) achievement.

Table 15 Result of trial for 45 heats cycle-repair

Ladle #3



Lining					
Wall	ALTIMA	ALTIMA	ALTIMA	ALTIMA
Bottom	ALTIMA+LBA-8	ALTIMA+LBA-8	Zircon & High alumina (Conv.)	ALTIMA+LBA-8
Well block	Alumina-Magnesia	Alumina-Magnesia	High alumina (Conv.)	Burnt Alumina-Magnesia

Repair				
Heats	42(after repair) / 42(total)	43(after repair) / 85(total)	22(after repair) / 107(total)	55(after repair) / 151(total)
Critical wear for repair	Damage of well block	Damage of well block	Damage of well block	Damage of brick around well block Optimization of replacement area enables 45 heats
Repair methods	<Brick replacement> Bottom brick Well block	<Brick replacement> Bottom brick Well block	<Brick replacement> 4 courses of impact side Bottom brick Well block	Whole brick replacement after complete dismantling

Table 16 Summary for achievements of trials

Area	Materials	Target life	Trial result	Conventional	
Wall	Alumina-Magnesia (ALTIMA)	180 heats	Achieved	Zircon	90 — 100 heats
Wall Impact area	Alumina-Magnesia (ALTIMA)	90 heats ×2	Achieved with troweling repair	Zircon	45 — 50 heats ×2
Bottom	Impact area; Alumina-Magnesia (ALTIMA) General area; High alumina (LBA-8)	45 heats ×4	Achieved	Impact area; Zircon General area; High alumina	20 — 25 heats ×4
Well block	Burnt Alumina-Magnesia (AMP-8Y2PBB)	45 heats ×4	Achieved	High alumina	25 heats ×2
Local wear Wall / Bottom	Troweling repair material (SSC-AM340T)	7 to 8 times	Applicable to local wear	-	-

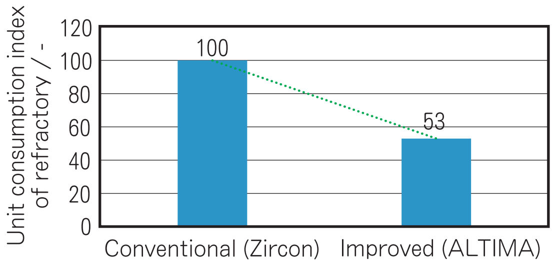


Fig. 8 Comparison of overall unit consumption of refractory.

trial results showed that 45 heat cycle-repairs became possible.

5. Summary of Service Life Extension Trials

The results of the life extension tests are shown in Table 16. As described in section 2.1, the service life of conventional zircon lining ladle was 100 heats with 25 heat cycle-minor repairs. As a result of the trials, a service life of 180 heats with 45 heat cycle-minor repair became possible with the new lining, which consists of ALTIMA for the side wall and bottom impact area, and LBA-8 for the general zone of bottom and fired well block made of alumina-magnesia composition. This improvement reduced the specific cost of ladle refractories 47 % as shown in Fig. 8.

6. Conclusion

In order to extend the life of the steel ladle and to achieve stable durability, ALTIMA brick, which is an unfired alumina-magnesia brick, was tested as an alternative to conventional zircon brick. In addition, alumina-magnesia troweling material was also applied as a repair material used for local damage of the well block and the hot impact area.

As a result, the following conclusions were obtained.

1) Service life was improved from 100 heats with 25 heat cycle-minor repairs to 180 heats with 45 heat cycle-minor repairs.
2) The overall specific cost index of the steel ladle reduced by 47 %.
3) The frequency of repair, dismantling and construction of the ladle was reduced, which enabled easier repair planning. This contributed to improvement of workability as well as productivity.

For the future, we will continue to improve ladle refractories to extend service life to 200 heats.

7. Acknowledgment

The improvement described in this report was achieved by working together with Showa Denro Kogyo Co., Ltd. and Shinagawa Refractories Co., Ltd. We extend our appreciation to those two companies.