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Managing the tap-hole life-cycle at five submerged arc furnaces producing silicomanganese at Transalloys

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Transalloys, South Africa

Transalloys is a silicomanganese (SiMn) producer located in South Africa, and uses local manganese ores to produce SiMn alloy. The plant operates five open submerged arc furnaces (SAFs) with an annual capacity of 180 000 t of saleable SiMn.

Tap-hole maintenance is critical to effective furnace operation, allowing proper drainage of the furnace with minimal operator interference. Using a clay gun and drill arrangement installed at each furnace, tapping occurs every four hours. Tap-holes are maintained through mickey replacement and brick repairs. Three furnaces have SiC tap-holes and two furnaces have graphite tap-holes.

This paper reviews submerged arc furnace (SAF) operation, furnace and tap-hole design, daily tapping operation, and maintenance practices for repairing tap-holes.

Keywords: tap-hole, life-cycle, submerged arc furnace, silicomanganese, Transalloys.

INTRODUCTION

Defining tap-hole life cycle, Steenkamp *et al* (2016) highlighted four main steps: installation during furnace relines, day-to-day operations, tap-hole maintenance, and tap-hole repair. The authors argued that the design of the tap-hole area should take into account all four stages in the tap-hole life-cycle. Design principles for each stage were presented using producing silicomanganese (SiMn) as a case study. Here we present a further analysis of the case study by providing practical examples of how the tap-hole life-cycle is managed at Transalloys during design, operation, and maintenance of submerged arc furnaces (SAFs) for the production of SiMn.

BACKGROUND

Transalloys is the largest producer of SiMn in Africa. Its smelter complex is based outside the town of eMalahleni, in the Mpumalanga Province of South Africa. Transalloys was commissioned in the mid-1960s as a high- and low-carbon ferrochromium plant based on the Perrin Process. In 1967 the plant was converted to SiMn production because of constraints in the ferrochrome market (Basson, Curr, and Gericke, 2007; Bezemer, 1995). Today, the installed production capacity is 180 000 t of SiMn annually. Plant operations consist of five SAFs (see ratings in Table I), operating 24 hours a day, 365 days a year (including maintenance), with 280 permanent employees and up to 120 contract employees on-site at any given time.

Table I. Power ratings per furnace at Transalloys.

Furnace	F1	F3	F5	F6	F7
MVA rating	15	22	48	30	48
MW	14	14	28	16	28

In the SAFs (see Figure 1 for a layout), SiMn is produced by carbothermic reduction of manganese-bearing ore, which is sourced from the Kalahari Manganese Field in the Northern Cape Province. Quartz is sourced locally from South African producers. The main source of carbon is bituminous coal from South African coal mines, with imported coke also used. The specification of the SiMn alloy produced is 65% Mn, 16% Si, < 2% C, with Fe making up the balance. SiMn is used as an alloying component to produce many different grades of steel.

The SAFs are open to the atmosphere and process off-gas is combusted on top of the burden, from where it is cooled and cleaned through a baghouse system before venting to the atmosphere. A mix of slag and alloy is cascade-tapped into alloy ladles and slag pots from a single tap-hole every four hours. Alloy and slag are separated post-tapping by cascade tapping and then removing slag from the alloy ladle with a slag scraper. Alloy is then layer cast in cast beds and slag is discarded onto slag dumps. The slag-to-alloy ratio is typically 1.0 to 1.3. Typical slag compositions are shown in Table II.

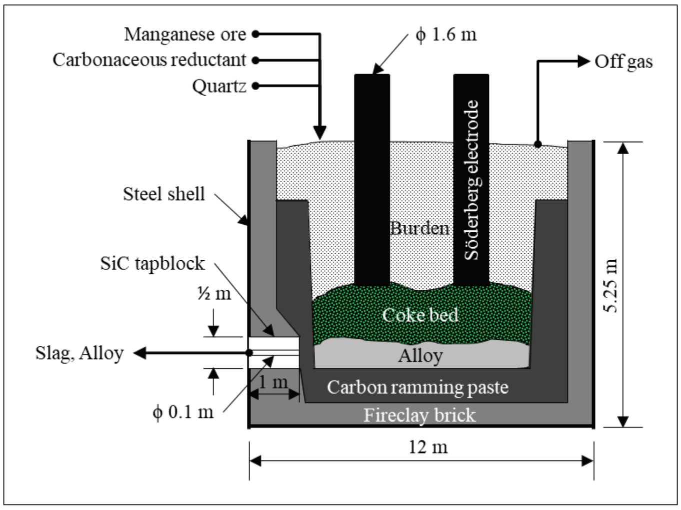


Figure 1. Conceptual layout of an open submerged arc furnace producing silicomanganese at Transalloys (sketch provided by Joalet D. Steenkamp).

In submerged arc furnace operation all three electrodes are covered by raw materials. Manganese enters as Mn_2O_3 and Mn_3O_4 and is prereduced in the upper layers of the furnace to MnO by CO gas permeating through the furnace burden. Final conversion of MnO to Mn and SiO_2 to Si takes place in the coke bed below each electrode, as seen in Figure 1.

Table II. Typical tapped slag compositions (%by mass, 2669 samples, by XRF).

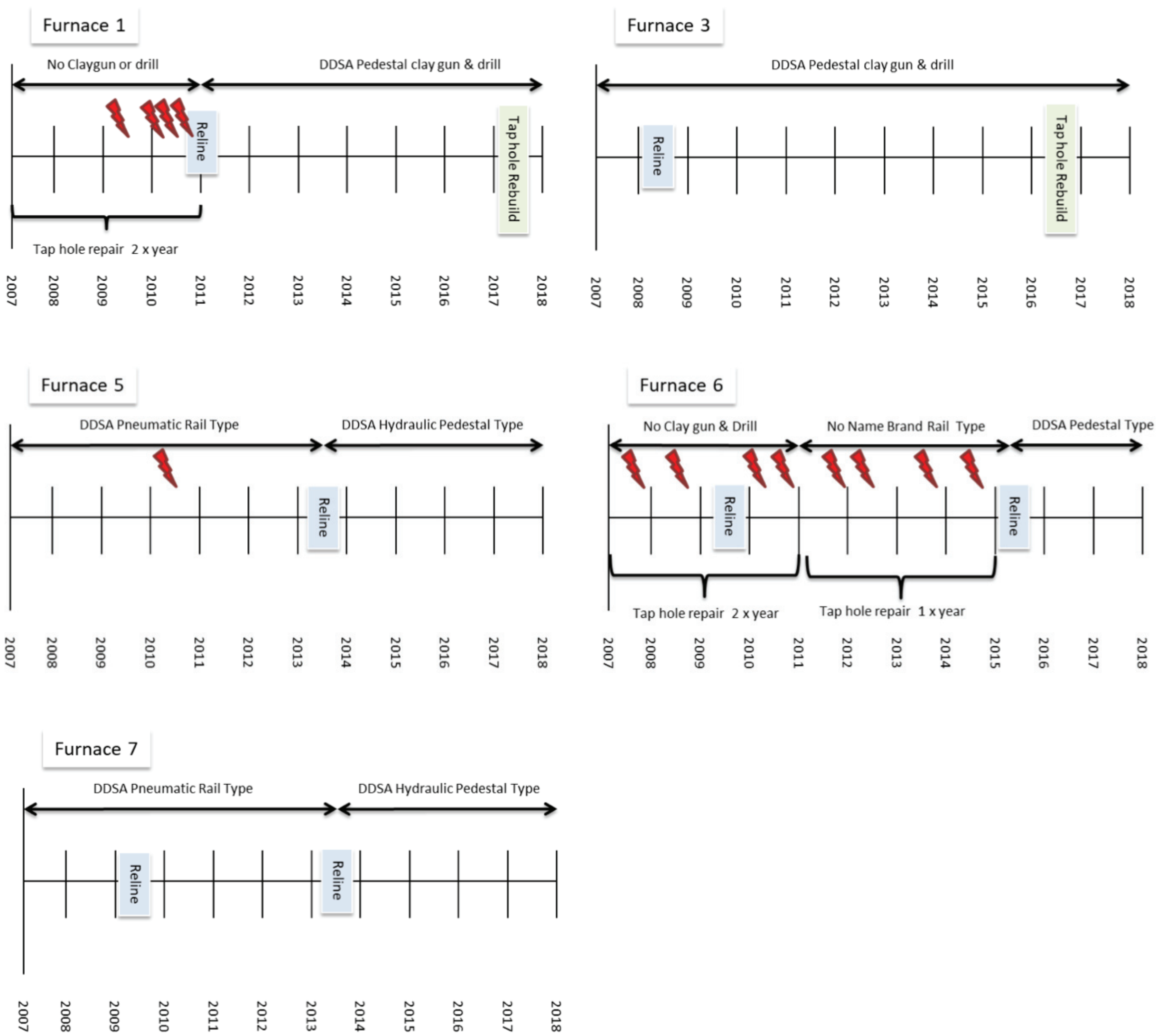
	MnO	SiO2	MgO	CaO	FeO	Al_2O_3	B-ratio
Av.	10.73	43.28	7.31	31.94	0.41	4.31	0.91
Std dev.	±1.55	±0.92	±0.33	±1.17	±0.14	±0.30	±0.04

MANAGING THE LIFE-CYLE

In this section the tap-hole designs are discussed. Table III provides a summary of the furnace refractory design and tap-hole design of each furnace.

Table III. Summary of furnace refractory and tap-hole design and timelines for tap-hole repairs.

Furnace	Furnace refractory design	Tap-hole design	Tap-hole cooling	Clay gun type
1	Insulating lining	SiC bricks	Natural air cooling	Pedestal-mounted
3	Semi-freeze lining	SiC bricks	Forced channel water cooling	Rail-mounted
5	Semi-freeze lining	Graphite block	Forced channel water cooling	Pedestal-mounted
6	Insulating lining	SiC block	Natural air cooling	Pedestal-mounted
7	Semi-freeze lining	Graphite block	Forced channel water cooling	Pedestal-mounted



A 'semi-freeze' lining at Transalloys refers to two concepts used in the same furnace. Different areas in the furnace are either build as a freeze lining and other areas as insulating lining as follows.

- The sidewall areas around the tap-holes are graphite bricks with graphite tiles against the shell – a classic freeze-lining concept.
- The rest of the sidewalls have a graphite tile against the shell and then a 60 alumina brick as a working lining – standard insulating lining.
- On the hearth two layers of carbon blocks are installed; but beneath these block are nine layers of high-alumina bricks (three layers each of 85 alumina, 90 alumina, and tab alumina) – a combination of freeze and insulating lining.
- On top of the two layers of carbon blocks a 600 mm carbon ramming is also installed – this is a standard lining design for ferroalloy furnaces.

Why silicon carbide and carbon tap-holes?

Alloys produced at Transalloys are either C-saturated or SiC-saturated, depending on the silicon grade of the alloy (see Figure 3) (Steenkamp *et al.*, 2016)

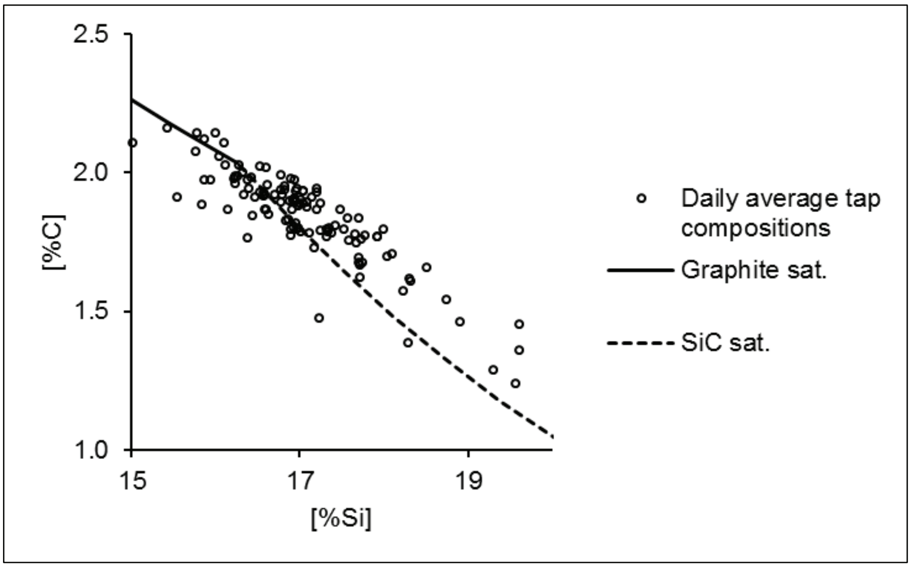


Figure 3. Carbon solubility in Mn-Fe-Si-C alloys with Mn:Fe mass ratio of 4.47 at 1600°C, calculated with FactSage 6.4 (FSstel database); compositions given as mass percentages. For silicon contents below the inflection in the curve, the stable solid phase at saturation is graphite; SiC is the stable phase at saturation for higher silicon contents. The symbols show reported daily average SiMn compositions over a four-month period. (Steenkamp et al., 2016).

During excavation of a 48 MVA submerged arc furnace at Transalloys, two high-wear areas were found: the tap-hole area and the furnace hearth (Gous *et al.*, 2014). Carbon-based refractory material formed the hot face refractory. Analysis of daily average tapped slag and metal compositions produced in the four months prior to the excavation confirmed the potential for refractory wear through C dissolution in the metal (see Figure 3) and SiC formation by chemical reaction with SiO_2 in the slag.

Design

All five furnaces have one single-level tap-hole. Metal and slag are tapped simultaneously through the tap-hole every four hours. The furnace crucible is 3–4 m deep and the tap-holes are 200 mm above the hearth floor.

In 2008 only one furnace had a proper clay gun and drill, and frequent tap-hole failures occurred on all furnaces. Tap-holes were lanced open with oxygen and closed by hand using a 'dolly' (see Figures 10a and 10b). In an effort to improve tap-hole life two design philosophies were introduced, as shown in Table III, mainly to address tap-hole problems. The first was a semi-freeze lining design where tap-hole cooling was the key concept, and second an insulating design using high-wear refractory. Both these designs stemmed from a need to ensure better tap-hole life as well as easy repair once a tap-hole failed.

Semi-Freeze Lining Design

On furnaces 5 and 7 with the semi-freeze lining design, graphite tap-blocks are installed. Figure 4 shows a typical graphite tap-block design consisting of a carbon block (600 mm × 600 mm × 800 mm), two graphite lintels (350 mm × 300 mm × 800 mm), and three sacrificial mickeys (600 mm × 600 mm × 170 mm) on the working face with carbon bricks surrounding the tap-block.

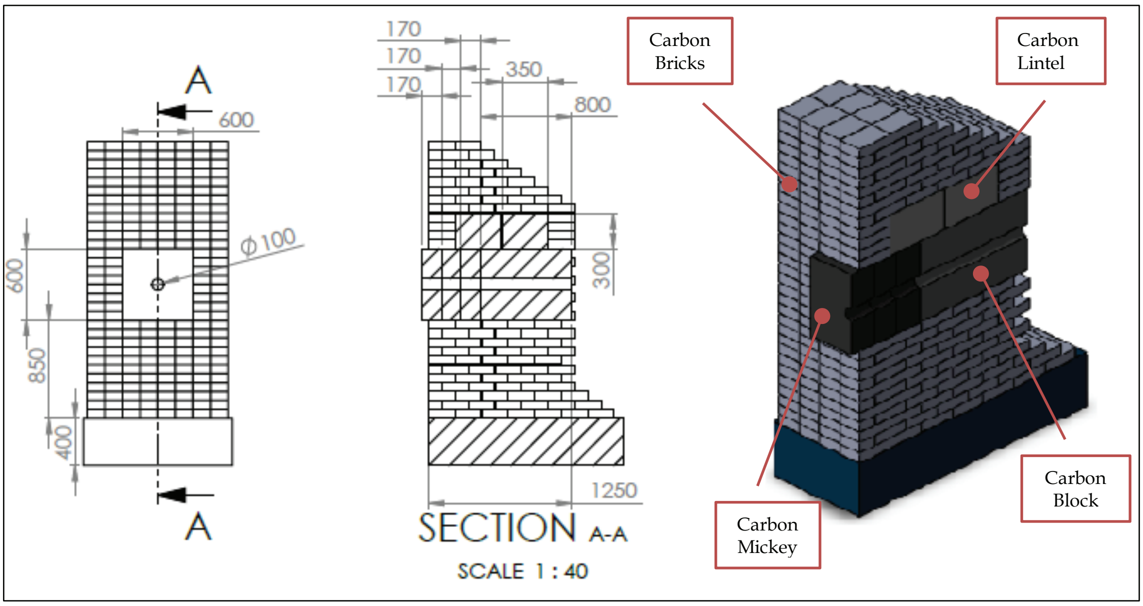


Figure 4. Schematics of graphite tap-block design (redrawn from original drawings and photographs of actual installation by Driaan Bezuidenhout).

Figure 5a shows the staggered design on the sidewalls of furnace 3, allowing for optimal contact between the sidewall carbon ramming (Figure 5c) and the carbon bricks surrounding the tap-block. In the semi-freeze lining design the tap-blocks, lintels, and mickeys are surrounded by carbon bricks (Figures 5b and 5d), allowing for maximum heat removal through external water cooling channels as shown in Figure 5f. The outside of a carbon tap-hole showing the installed mickey and the launder flange is shown in Figure 5e

Figure 5b shows the installed carbon ramming on the furnace floor (800 mm thick). The carbon ramming is taken up to 200 mm below the tap-hole. When completed, a sidewall ramming is installed (800 mm wide) as shown in Figure 5c, covering the tap- hole graphite bricks. A drilling depth of 2 m is required to open a tap-hole.

Figure 5f shows the tapping launder installed in position; notice a slight bend 2 m from the tap-hole. This allow for the tappers to lance and poke the tap-hole in a direct line with the tap-hole to prevent unnecessary damage to the carbon block. Figure 5d shows the front sacrificial mickey and flange as installed. The tapping launder is bolted onto the tap-hole flange.

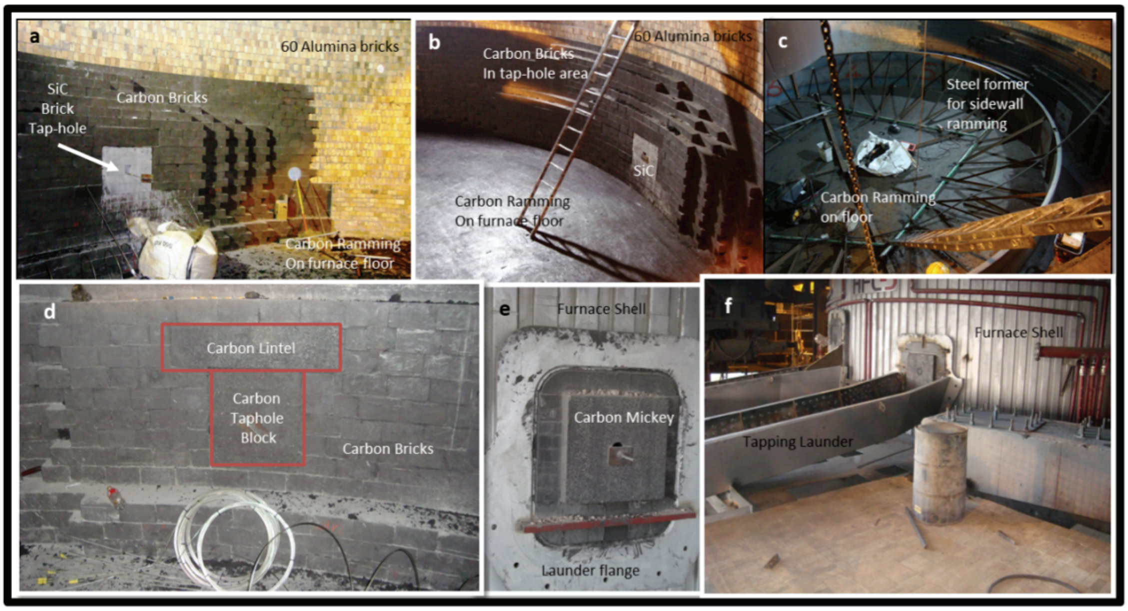


Figure 5. (a) Inside of tap-hole showing the staggered design of graphite bricks and a SiC brick tap-hole; (b) sacrificial carbon ramming on hearth and carbon tap-hole wall before sidewall ramming is installed; (c) former for sidewall ramming installed; (d) carbon tap-hole showing carbon tap-hole block and carbon lintel; (e) outside view of carbon tap-hole showing carbon mickey installed; (f) water cooling channels on furnace shell, front mickey, and launder flange with curved launder design.

Insulating Lining Design

Furnaces 1 and 6 have an insulating refractory design with no external water cooling on the furnace shell. In this design the tap-hole is constructed with SiC blocks, SiC bricks, and a SiC lintel. Figure 6 shows a typical SiC tap-hole design consisting of a two SiC blocks (600 mm × 600 mm × 600 mm) and two SiC lintels (300 mm × 800 mm × 300 mm). Lintels are installed on the inside of the tap-hole to maintain the integrity of the sidewall. When the tap-block wears only the tap-hole block can be removed with careful demolition, and then a new tap-hole block can be inserted (similar to the carbon block installation in Figure 12)

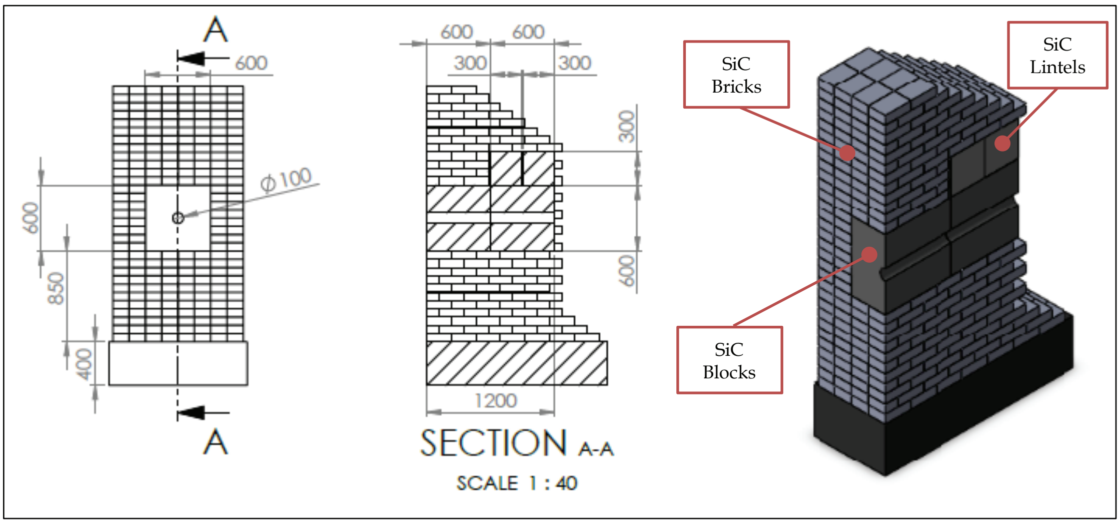


Figure 6. Schematics of SiC tap-hole design (redrawn from original drawings and photographs of actual installation by Driaan Bezuidenhout).

Figure 7a shows the square block tap-hole design (Furnace 1). The tap-block area consists of SiC bricks, whereas the rest of the furnace wall consists of SiO_2/Al_2O_3 bricks. Figure

7b shows a staggered design of the bricks on the sidewall of furnace 6, allowing for improved contact between the sacrificial carbon ramming wall (not yet installed) and the SiC bricks around the tap-hole. .

Figure 7b shows the sacrificial carbon ramming on the furnace floor (600 mm thick). The ramming is taken up to 200 mm below the tap-hole. A steel pipe is inserted into the tap-hole in order to keep the tap-hole free from any obstructions and to facilitate the opening during the first tap after start-up. When completed, a sacrificial sidewall ramming is installed (600 mm wide) as shown in Figure 5c, covering the SiC bricks forming the tap-block. A drill depth of at 1.8 m is required to open a tap-hole.

Figure 7d shows configuration of bricks on the outside of the tap-hole. The faceplate and tap-hole flange where the tapping launder will be bolted onto are shown.

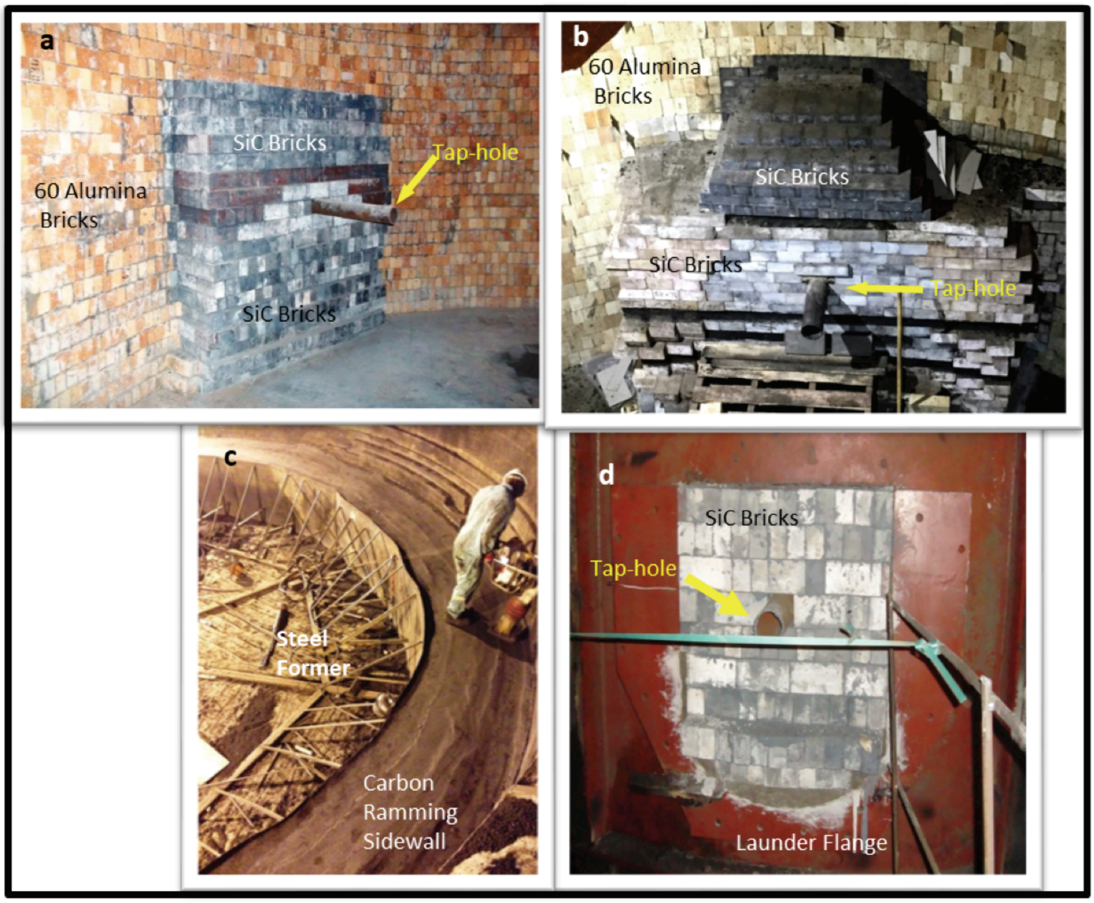


Figure 7. (a) Square SiC tap-hole design inside carbon bricks; (b) inside of tap-hole showing the staggered design of SiC bricks ; (c) sidewall carbon ramming being installed; (d) outside view of SiC bricked tap-hole.

Hybrid Design

Furnace 3 also has a semi-freeze lining design with external water cooling but with a SiC tap-hole. This tap-hole proved to be the most durable and only minor repairs were required in the eight years since the furnace was relined in 2008.

TAP-HOLE OPERATIONS DAY-TO-DAY

All furnaces are equipped with a separate hydraulic clay gun and drill supplied by Dango & Dienenthal SA (Pty) (Ltd). Figure 8a shows a pedestal-type clay gun and drill, four of which are installed at Transalloys, and Figure 8b a rail-type clay gun and drill, only one of which is in use. Drill bits used to open tap-holes are 76 mm in diameter and on average the drilling depths are between 1.5 and 2 m. This section will focus on the opening of tap-holes, tapping of furnace, closing of the tap-hole, and general tap floor operation and equipment.

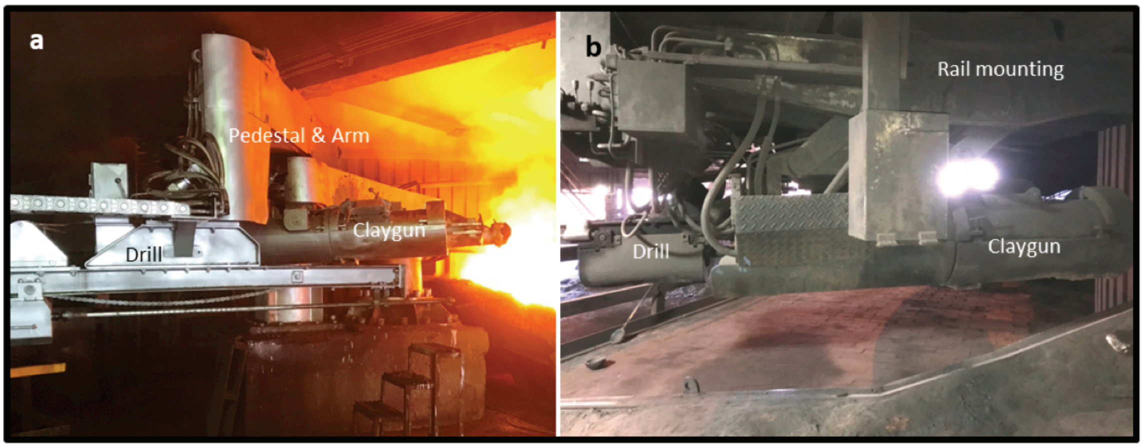


Figure 8. (a) Pedestal clay gun and drill; (b) rail-type clay gun and drill.

Opening of tap-hole

Furnaces are tapped six times a day at fixed intervals of four hours. Each tap lasts approximately 30 minutes. A hydraulic tap-hole drill is used to drill open the tap-hole. The success of opening a tap-hole depends largely on the proper closing of the tap-hole after the previous tap. The tap-hole is considered to be properly plugged when the entire length of the tap-hole is filled with tap-hole clay and no slag or metal is frozen inside the tap-hole.

Before drilling the tap-hole several important aspects need to be inspected and verified to reduce the risk of anything going wrong during the tapping process. Firstly, the drill bit is inspected to ascertain whether it is still sharp enough to 'cut' the tap-hole open as opposed to only 'pushing' it open. Secondly, the airflow through the centre of the extension rod is tested to confirm there is adequate flow to blow out the debris that is formed during the drilling process, as well as assisting in the cooling of the drill bit and extension rod during drilling. It is important that the drilling debris be blown out of the tap-hole when drilling. If this is not the case the drill bit can get stuck. Thirdly and most critically, the drill must be aligned with the tap-hole. If this alignment is not perfect a 'new' tap-hole will be drilled, and this can lead to difficulties with closure as the clay gun will most probable not be aligned with the 'new' tap-hole

In case of the tap-hole not opening by drilling an oxygen lance is used to open the tap-hole. Lancing of the tap-hole should be kept to a minimum due the fact that oxygen lancing reduces the life of the tap-hole considerably by oxidizing the refractory material.

The tap-hole should be lanced on the same level and in the same direction as the drilling equipment used to open the tap-hole. This is to prevent the creation of secondary tap-holes, especially towards the back of the tap-hole. The design of the tap floor should be such that a person of average height holding the oxygen lance in a comfortable position should be able to lance horizontally. The launders are therefore slightly curved approximately 2 m from the tap-hole to enable the tapper to stand directly in front the tap-hole when lancing.

Only moderate oxygen pressure is required to lance through solidified slag and metal. If the pressure is too high the tap-hole wear will be increased exponentially due to increased oxidation. Additionally, due to the large amount of oxygen blown into the tap-hole there is a correspondingly large amount of gas exiting the tap-hole. This gas serves as a carrier gas for pieces of slag, alloy, or raw materials, which move at high velocities and can potentially cause serious injuries to persons standing on the tap floor.

However, when the oxygen pressure is too low the opening of the tap-hole is very time-consuming and slag and alloy are not blown out of the tap-hole effectively. The metal and slag then solidify in the tap-hole channel and an excessive amount of oxygen will be required to open the tap-hole channel. Oxidation then occurs towards the front of the tap-hole. This wear can lead to 'rat-hole' formation in the sidewall if the wear is not controlled properly. In this case the tap-hole cannot be drilled open. If drilling is attempted, the utmost care must be taken that the drill bit does not deviate from the normal path when drilling into the metal; for example, when the drill extension moves upwards in the tap-hole when drilling. This causes 'new' holes to be drilled and perforate the tap-block, reducing the life of the tap-block dramatically.

Once the tap-hole is open, it is good practice to maintain a good flow of alloy and slag by using a poker bar to keep the tap-hole open and the flow unrestricted. A poker bar is also a good tool for removing pieces of raw material or electrode that get stuck in the tap-hole.

Managing Alloy and Slag Flow

If the alloy and slag flow is strong and uninterrupted, minimal interference from the tappers is required. Occasionally the flow is slowed down by raw material mix obstructing the tap-hole. A poking bar is then used to clear the obstruction. Bigger obstructions like electrode pieces, bricks, and hardened tap-hole clay are sometimes difficult to remove with a poking bar. Then oxygen lancing is required to enlarge the tap-hole to remove the obstacles. It is important to remove the obstacles continuously to ensure proper drainage of the furnace and to allow for proper closing of the tap-hole.

If obstacles are not removed from the tap-hole, the plugging of the tap-hole will be inefficient. At the next tap the tap-hole will be full of frozen alloy and slag, and excessive lancing will be required. This increases tap-hole wear and in extreme cases the integrity of the tap-hole will be compromised when sidewall bricks start to collapse into the tap-hole.

The furnace is an integrated system and poor electrode management can adversely affect the life of a tap-hole, due to broken-off electrode pieces blocking off the tap-hole and requiring excessive lancing. Operators need to understand that good electrode management is of utmost importance to prevent electrode tip losses that will cause blockages in the tap-hole.

Closing of tap-hole

Effectively closing the tap-hole after each tap means that the full length of the tap-hole should be filled with tap-hole clay to ensure proper contact between the tap-hole sidewalls and the new tap-hole paste. This will prevent the tap-hole from opening unexpectedly between taps due to pressure from the slag and metal inside the furnace pushing the tap-hole clay out of the tap-hole or leaking between the tap-hole clay and the tap-hole sidewall occurs.

Clay guns should always be fully loaded and properly prepared before the tap-hole is opened, as shown in Figure 9a. The aim is for the clay to immediately push into the tap-hole to displace metal and slag as soon as the clay gun piston starts pushing forward.

The preparation of the clay gun is aimed at preventing alloy from damaging the nozzle tip and to create a proper seal between the tap-hole and the clay gun tip. During the loading and preparation of the clay gun the tap-hole clay in the clay gun barrel must be compressed to eliminate any voids. This is done by pressing the clay gun against the tap-hole (when closed) and pushing the cylinder forward until clay is pushed out between the clay gun tip and the tap-hole. This signifies that the tap-hole clay in the clay gun is fully compressed. Omitting this increases the risk of burning the clay gun nozzle when closing the tap-hole against a full stream of alloy. When closing the tap-hole against a full stream of alloy there will be a period when the cylinder is pushing clay forward but no clay is coming out of the nozzle and into the tap-hole, while voids in the barrel are being filled. Even if this is for only a few seconds, when the furnace is tapping strongly the nozzle will burn and the tap-hole cannot be closed. The furnace will continue tapping, possibly causing damage to downstream equipment and injuries to people. The tapping personnel should always be prepared for the worst case, and this simple act performed in a disciplined manner can prevent damage when it is least expected. These types of emergencies can include launder penetration, ladle penetration or tapping over the launder, an electrode break, or many other risks in the day-to-day operation.

As discussed, the alignment of the clay gun and drill with the tap-hole is critical and must be checked on a daily basis. The nozzle tip needs to fit tightly around the centre of the tap-hole ensuring that the full clay stream enters the tap-hole without squeezing out at the sides of the clay gun tip.

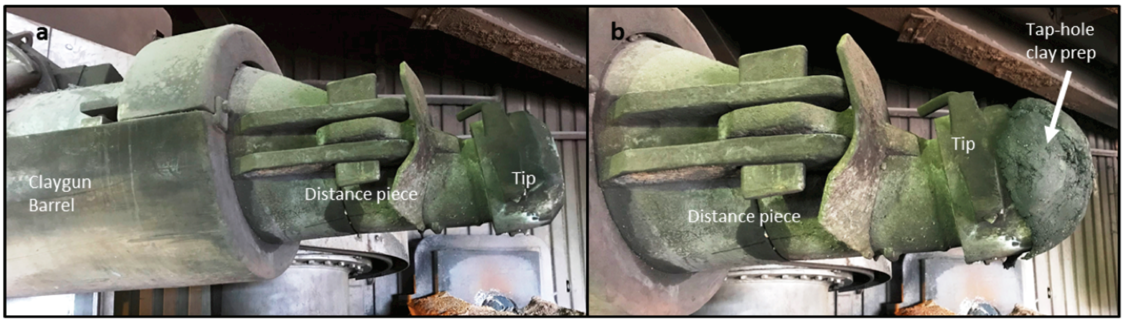


Figure 9. (a) Primed clay gun; (b) clay gun nozzle; (c) clay gun nozzle tip.

Three types of CTPV-free tap-hole clays are used at Transalloys, namely low-cost (low quality), intermediate-cost (standard quality), and high-cost tap-hole clay (high quality). A summary of the chemical compositions of the different types of clays used is given in table IV. Only the intermediate and high-cost types have the properties needed to rebuild a damaged or worn tap-hole. To control operational costs, low-cost clay is used in normal day-to-day operations with the expectation there will be some wear of the tap-hole. Good tap-hole practice can delay this wear; the tap-hole clay quality affects not only the tap-hole integrity, but all the aspects around the tap-hole operations. When the tap-hole is starting to wear beyond a certain limit a switch is made to the intermediate-cost tap-hole clay with the aim of restoring the tap-hole condition. If serious tap-hole problems occur, *e.g.* when bricks in the tap-hole fall out, the expensive tap-hole clay is used to repair the damage. A practical approach to tap-hole management must consider the cost of the tap-hole clay and the integrity of the tap-hole.

Table IV. Chemical composition of different types of tap-hole clays used at Transalloys.

	Al_2O_3 (%)	SiO_2 (%)	SiC (%)
Low cost	5.9	77.2	0
Moderate cost	16	69	0
Expensive	63.5	18.7	14.5

Tap Floor Activities

Launders are cleaned after every second tap and re-dressed with river sand (see Figure 10g). Launder sand protects the carbon ramming on the launder and also makes it easy to remove the slag and alloy from the launder.

Figures 10b, 10c, and 10d show some of the typical launder cleaning tools used on a tap floor. A bent oxygen pipe is used to remove alloy and slag build-ups after they have been loosened with a steel round bar. In case of the clay gun not being operational a dolly is used to close the tap-hole manually. Figure 10a shows a former used to create a tap-hole clay plug to be used when closing the tap-hole manually.

The steel launder is normally lined with used refractory bricks of any quality used at Transalloys (alumina, SiC, or carbon bricks (Figure 10f), then covered carbon ramming material and finally with a layer of sand (see Figure 10g). The sand makes the cleaning of the launder easier since it is easier to insert a steel 'gwala' below the metal/slag skull through the sand layer and lift the skull out of the launder.

Launders are angled to allow for lancing and poking to be done parallel with tap-hole. A launder tip is attached to the front end of the launder (see Figure 10h). High wear-resistant castable refractory is used in the launder tip to withstand the eroding forces, especially from the alloy. The launder tip is fastened to the launder with wedges to allow for movement or a default line to prevent damage to the launder or launder flange at the furnace shell if a crane driver accidentally knocks the launder tip when removing or placing the ladle. Worn-out launder tips are replaced every three to four months to prevent alloy from damaging the top ring of the alloy ladles.

Figure 10. (a) Tap-hole clay former and ancillary equipment; b) redundant refractory bricks used on base of launder; (c) river sand used to dress launder;(d) removable launder tip.

TAP-HOLE AND HEARTH MAINTENANCE PROGRAMME

Monitoring of furnace hearth temperatures, visual inspections of tap-holes, drilling depth, tap-hole diameter, and tapping conditions are used to determine the tap-hole maintenance and repair schedule.

Previous excavations and lining failures indicated that the most problematic area in the SiMn production process is the wear of the hearth refractory in the clover area (PCD) under the furnace electrodes. Subsequently, all furnaces were equipped with several hearth thermocouples to monitor hearth temperatures. Table V shows typical life-cycles of relines and tap-hole repairs for each furnace at Transalloys. Time intervals may be shorter than those indicated in cases of catastrophic lining failures or excessive O_2 lancing that will reduce the life of a tap-hole. Long downtimes (in excess of 3 months) can also lead to lining failures due to uneven contraction and expansion of the hearth and sidewall refractories.

Telltale signs that indicates that a tap-hole rebuild is imminent are refractory bricks coming out of the tap-hole, furnace tapping raw material mix at regular intervals, an increase in tap-hole clay usage, and less than 1 m drilling required to open the tap-hole. Tap-hole life can be extended by using expensive, high-quality clay containing SiC (see Table III). This can buy time to properly plan for a tap-hole rebuild or repair.

Table V. Typical furnace reline, tap-hole rebuild, and tap-hole repair timelines.

Furnace	Complete or partial furnace reline	Tap-hole rebuild	Tap-hole repair
1	8 years	4 years	2 years – replace only front SiC block
3	12 years	6 years	3 years – replace only front SiC block
5	12 years	6 years	6 months – only front mickey replacement
6	8 years	4 years	2 years – replace only front SiC block
7	12 years	6 years	6 months – only front mickey replacement

A complete furnace reline implies a total excavation of the furnace and replacement of all refractories including sidewall, hearth, and tap-hole. A partial reline requires only the replacement of the sacrificial carbon ramming on the furnace floor. This will also allow the tap-hole to be repaired from the inside of the furnace. Excavation of the furnace burden and subsequent visual inspection of the furnace lining will determine the extent of the rebuild or repair.

Tap-hole Rebuild

Figure 11 shows the steps in the rebuilding of a SiC tap-hole. A rebuild is completed in four days (from furnace switch-out to first tap), including the warming up of the tap-hole refractories.

Before switching out the furnace for a tap-hole rebuild the furnace needs to be melted down as far as possible, which will reduce the amount of loose furnace burden that has to be removed from the tap-hole. The sequence of events after the last tap has been made and the furnace is switched out is as follows: cooling down for 12 hours, removal of tapping launder, installation of a working platform in front of the tap-hole, removal of tap-hole faceplate to expose tap-hole refractories, breaking out of tap-hole refractories with Brokk machine, and allowing remaining molten slag and metal to drain from the furnace (see Figure 11a). During the breaking out of the refractory and removal of loose burden and solidified slag, water cooling is applied to increase the rate at which the tap-hole area is cooled down. Final breaking out of tap-hole bricks is done carefully with a jackhammer to expose undamaged tap-hole bricks that will form a clean surface to tie-in the new refractory bricks.

Figures 11b, 11c, and 11d show the installations of the SiC blocks, lintels, and SiC bricks in Furnace 1. The bricks below the block are started from a solid foundation or good floor. After the rebuild of the tap-hole is completed, the faceplate and launder flange are replaced. A steel pipe is placed in the tap-hole and plugged with a small piece of tap-hole clay at the hot face of the pipe to assist with the opening of the first tap after start-up. After the launder has been replaced, the tap-hole bricks are extended into the launder and then rammed with carbon material. It is of utmost importance to check the alignment of the clay gun and drill after a tap-hole rebuild.

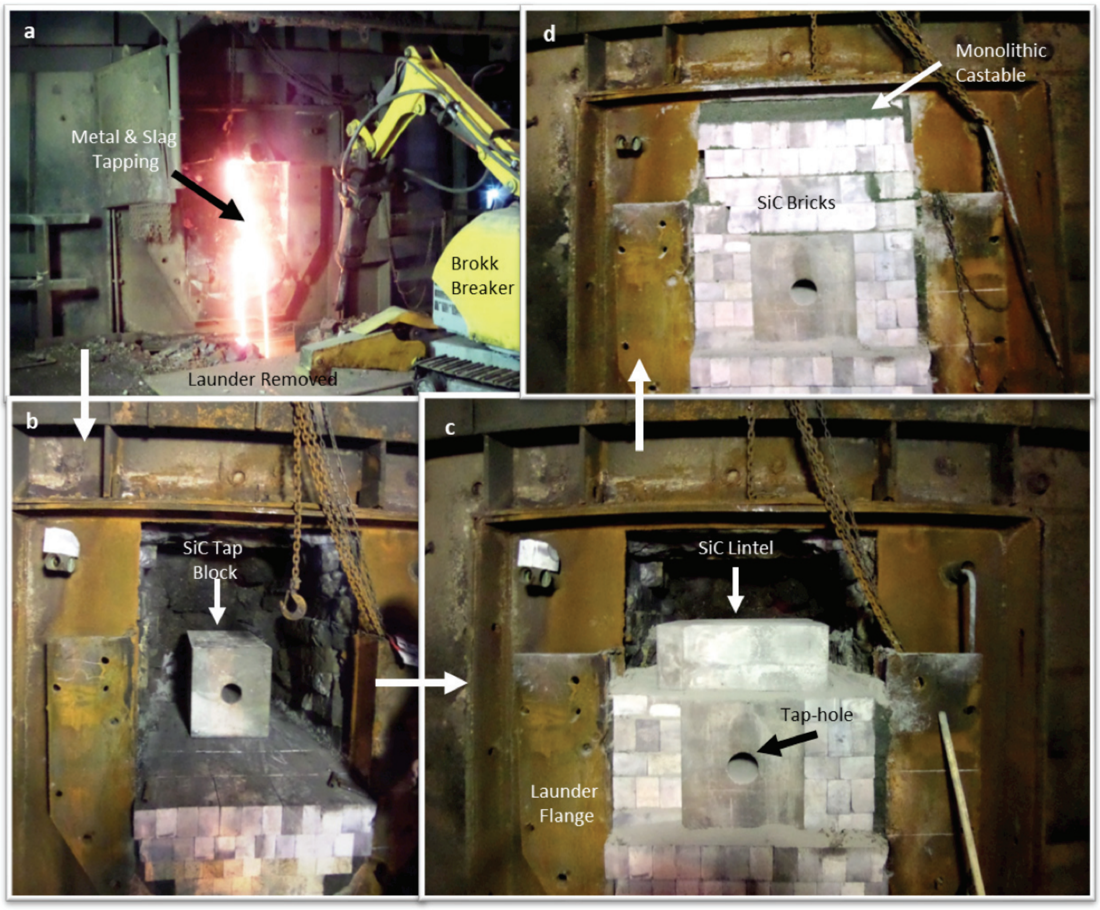


Figure 11. (a) Brok machine breaking out tap-hole; (b) placing of first SiC block; (c) two SiC blocks with SiC lintels; (d) repaired faceplate and tap-hole flange.

In order for the newly build tap-hole to cure and bake properly the furnace is switched in in STAR mode to allow for the gradual heating-up of tap-hole refractories over 24 hour. The same methodology is followed after a rebuild of a graphite block tap-hole.

Tap-hole Repair

Under normal conditions, repairing a graphite tap-block entails only the replacement of the front sacrificial mickey. This can be done on an eight-hour planned shutdown. The launder sand and refractory materials in the launder are cleaned out with a jackhammer and shovel to expose the full mickey.

The old mickey is then removed by breaking it out with a jackhammer (Figure 12a) and replaced with a new micky (see Figure 12b). Removal of the first mickey allows for inspection of the second mickey and if required it can also be replaced.

After the mickey has been replaced, a 20 mm steel plate is installed over the mickey to keep it in position (see Figure 12c). Carbon ramming material is then used to line the launder up to the tap-hole again (see Figure 12d). A new mickey does not require warming up before it can be used.

The same methodology is used when replacing the cold face SiC block. The estimate time for only replacing the cold face SiC-block is 12 hours.

Figure 12. (a) Breaking out of front graphite mickey with jackhammer; (b) installing new mickey; (c) steel plate over mickey holding it in position; (d) repairing launder with carbon ramming material.

Start-up after Maintenance and Repair

The commissioning of a furnace after a major reline normally takes 7 days. Power input per hour is regulated to allow heat soaking of refractories and carbon ramming, to drive off volatiles and moisture and to allow for expansion of refractories. Because the furnaces are open furnaces, the refractories cannot be heated with gas and the warming-up is carried out with electricity using the furnace transformers in STAR mode configuration until the first tap is made.

Gradual heating-up of furnace after a long shutdown (more than three months) is also important to allow for slow expansion of refractories. This type of warm-up is completed in three to five days.

CONCLUSIONS

The furnace linings at Transalloys are of an insulating and semi-freeze design. SiC blocks and graphite blocks are used. Procedures and systems have been established to ensure an optimum life-cycle of furnace linings, tap-holes, and auxiliary tapping equipment. All furnaces are equipped with clay guns and drills. Proper plugging of tap-holes and only selective oxygen lancing have extended tap-hole lives significantly. Well-established heating and warming-up schedules of newly build furnace linings and tap-holes allow for optimum drying, baking, and expansion of refractory material.

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