Maintenance and major repairs of tap-holes and tapping spouts

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The paper reviews the tapping process and the major wear mechanisms on the tap-hole, including wear from tapping tools. Measured temperatures in different tap-holes are related to choice of binder and material for repair pastes. The strength and disadvantage of carbon and silicon carbide materials are compared. Normal daily and weekly maintenance of tap-holes is described, together with the major repairs that are done during longer furnace shutdowns. The objective is to show that the type of repair and repair material needs to be adapted to each individual furnace.

Introduction

A well-functioning tap-hole and tapping spout are essential for most melting processes. Metal and slag should be drained from the furnace at a rate equal to or greater than production to avoid accumulation, which will reduce the metal recovery or lead to dangerous conditions for workers in the tapping area. It is also important to have tap-holes that can be closed quickly to avoid metal diverting into unwanted areas. In some processes, gases exit through worn tap-holes to the detriment of the work environment. This can be a huge problem in Si and FeSi production, where the temperature of SiO gas increases due to reaction with atmospheric oxygen.

The tapping process and the major wear mechanism on the tap-holes

According to Steenkamp (2013) the lining wear mechanisms in ferromanganese furnaces are corrosion, erosion, spalling, and densification. These mechanisms are also valid for most ferroalloy production. The same mechanisms, apart from densification, are also said to apply in the case of tap-holes (Steenkamp, 2013). Tap-hole corrosion proceeds by the dissolution of lining material by slag, metal, or alkalis, or by oxidation from oxygen or water vapour. The source of the oxygen could be the atmosphere or oxygen blown into the tap-hole, vapour from wood poles, or water leakages. Erosion is caused by the flow of metal, slag, solid material, or gas at high velocity abrading the lining material. Oxygen blown into the tap-hole is also a major contributor to erosion. Spalling is a result of mechanical stress, which may be due to high temperature gradients combined with thermal expansion of the material, mechanical force from sticking tap-hole tool, or small explosions from a tap-hole cannon.

Different types of tapping equipment and their advantages and disadvantages are listed in Table I. In several processes, most of the tap-hole wear results from these tools.

The worst type of equipment in this respect is oxygen tubes and lances. Oxygen is blown through a metal or ceramic tube into the tap-hole, where it ignites and burns with carbon or through oxidation of metals. This, together with the gases exiting the tap-hole, can result in temperatures above 3000°C (Kadkhodabeigi, 2010) which are above the melting point of most materials. In addition, high temperatures lead to rapid heat-up with high thermal stresses and spalling as a result, as well as erosion due to the high gas velocities. Another disadvantage of oxygen is that it easily follows cracks in the lining, which could form channels in several directions. Some furnaces utilize oxygen tubes as the only tapping equipment, and the tap-holes on these furnaces will need more maintenance and different maintenance routines compared to furnaces with several different types of tapping equipment installed.

Measured temperatures in and around tap-holes

There is a large difference between tap-holes that are water- or oil-cooled and those with air cooling. The water cooling components, which are often made of copper (Trapani, 2005) need to be kept at temperatures below 100°C so that adjoining material close to the cooling system does not significantly exceed than that temperature. This is a problem for normal carbon-bonded lining materials, which need around 500°C for the initial baking. Reaching this temperature can sometimes be a problem also on furnaces with air cooling. Figure 1 show a thermo-camera image of a repaired tap-hole where no measured temperature is above 221°C. Expected temperatures inside the tap-hole are also shown. On this furnace, additional heating was needed to achieve baking of the carbon-bonded material. If the measured temperature is close to 500°C, thermal insulation outside the tap-hole can bring the temperature to the required level.

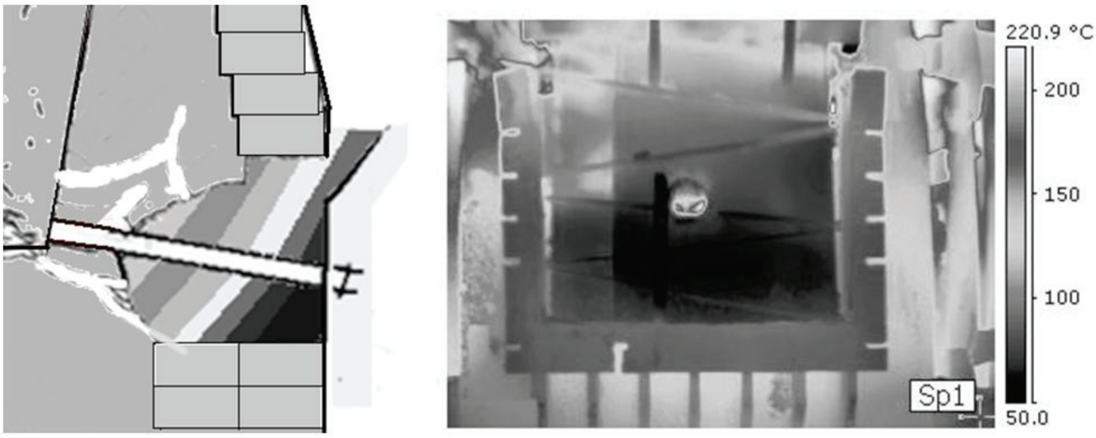

Figure 1. A thermo camera image (right) outside a repaired tap-hole 221°C is the highest measured temperature. To the left is a diagram of how the repair is carried out. Repair paste has been filled into the striped area, where the strips indicate the colours and temperatures that are shown in the thermo camera image

At low temperatures a resin-bonded paste could be a solution. With some additions the resin-bonded paste can attain the required strength at 130°C. However, if the furnace is too warm, the repair material can heat up too rapidly, resulting in a high porosity. On some FeSi furnaces, heat-up of repair paste to 800°C has taken less than 2 hours. This is too rapidly, and on these furnaces additional cooling fans should have been used.

Different carbon and silicon carbide lining/tap-hole materials

Carbon has many properties that make it well-suited for use in linings and tap-holes. The graphitic form of carbon is often used in bricks and finished parts, but in some applications amorphous carbon performs much better. Carbon is stable and retains its strength at temperatures exceeding 3000°C. Carbon materials with a high thermal conductivity and low thermal expansion are resistant to spalling (Rosenquist, 1983). The main limitation for carbon is that it burns in air, which becomes a problem at temperatures above 500°C. Most ferroalloys will also dissolve carbon to levels of several per cent. Mixtures of fireclay with carbon have good resistance to oxidation. The disadvantage of metal oxides is that slag and metal become more easily attached to the lining material. The wettability increases because slag/metal and metal oxide have similar surface potentials. This problem would normally become even worse with a lining material made of pure oxide.

Silicon carbide also has several properties that make it suited for use in linings and tap-holes. Thermal conductivity is high enough and thermal expansion is at a level to make this material resistant to spalling, although not as resistant as good graphitic material. Silicon carbide is stable to above 2600°C (Lindstad, 2002) and has a fairly good resistance to oxidation below 1500°C, being protected by a silica layer. Silicon carbide is not suitable for use with basic slags and alkali oxides, which attack the protective silica layer. Silicon carbide bricks can contain oxides as the binding phase. Furthermore, in this system the wettability between slag/metal and the refractory material increases. SiO_2 slag does not adhere to self-bonded silicon carbide (Lindstad, 1993).

Elkem Carbon's lining products are all manufactured from solid particles of carbon or silicon carbide and a pitch binder, resin binder, or a green binder. All Elkem Carbon lining products are within the chemical system C-Si-O(-H), from which almost all the hydrogen is emitted during the baking and curing process.

Most of the lining materials from Elkem Carbon are made from electrically calcined anthracite (ECA) heated to temperatures between 1000°C and 2500°C or higher (Seltveit, 1992). Anthracite is difficult to graphitize and the products contain around 30% graphite in the form of very small crystals. These materials inherit good properties from the both graphitic component (thermal and electrical conductivity) and the amorphous component (higher resistance erosion). The normal particle size is between 1 μm and 13 mm. The coarsest particles reduce corrosion and erosion, and normally the target for the size distribution is to achieve as high density as possible in the mixture. Another target is to avoid shrinkage of the material during baking and curing. Elkem Carbon also manufactures silicon carbide pastes with a size distribution of 4 mm and smaller. This paste was originally produced to form a dense layer to prevent gases emanating through the carbon lining from penetrating into the refractory bricks and weakening them.

Table I. This is showing the different tools that are used in the tap-hole with their positive effects and which negative mechanisms they contribute with

Equipment	Positive effect	Negative mechanism
Oxygen lance	Heat and gas pressure	Oxidation, corrosion, spalling
Wood poles	Gas pressure	Corrosion and spalling.
Taphole canon	Crush solid particles	Spalling
Steel bar	Removes solid	Spalling
Electrical stinger	Heat up taphole and stuck material	Corrosion
Drilling machine	Exact direction and diameter of tap-hole	Spalling
Paste(clay)Gun	Quick stop metal flow/Rebuild taphole	Make embankment

Different binders are used for production of self-flowing pastes and tamping pastes. Self-flowing pastes contain pitch with a softening point of 65-90°C, while tamping pastes contain binders with a softening point well below room temperature. This binder can also be a pitch binder, but resin or a new and totally non-toxic binder can also be used. Several of Elkem's self-flowing and tamping pastes are listed in Table II. Tamping pastes contain less binder than the free-flowing pastes. The viscosity of the binder will normally decrease during the first part of the baking process before the polymerization of the binder starts and the viscosity increases. Most of the hydrogen will be emitted as hydrocarbons and the binder phase becomes solid. With a pitch binder, the materials are quite solid when the temperatures reach 470°C. From 550°C the reactions slow down, but volatiles continue to be emitted and the binder carbonizes all the way up to 1000°C. The mass loss during heat-up of both a tamping paste and a self-flowing paste is shown in Figure 2. It can be seen that the tamping paste loses less mass and over a larger temperature range than the self-flowing paste. This is beneficial if the heating is rapid, because then a lower quantity of baking gases have longer time to leave the material compared to the self-flowing material. This will reduce porosity and increase density. Resin binders should be used if curing to 500°C is not possible before use. Resin with a hardener becomes solid from 130°C, but for this binder heating to higher temperatures is necessary to obtain a strong and more resistant binding phase.

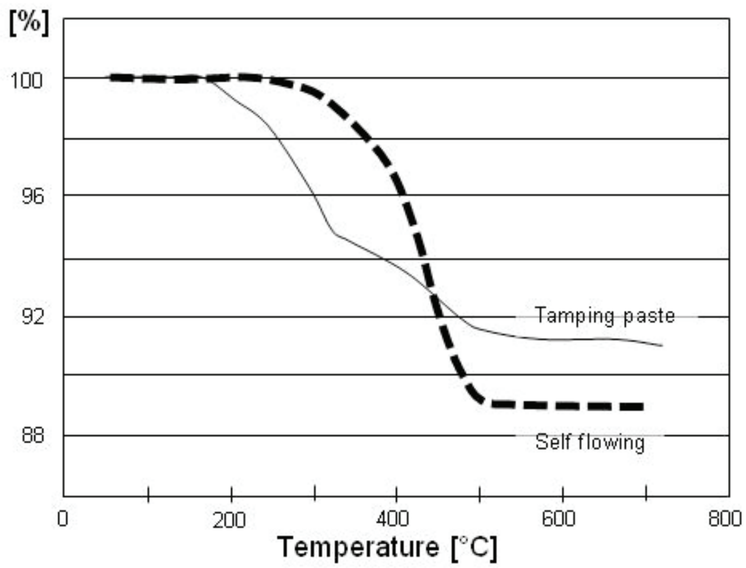

Figure 2. Weight loss during heat-up and baking for both tamping (type K) and a self-flowing material (type MA). The tamping paste loses weight in the temperature range 150-550°C, with the largest loss around 280°C. The self-flowing paste loses weight in the temperature range 280-520°C, with the largest loss around 440°C

For lining and repair pastes containing mainly carbon, curing to 1000°C brings out the best of properties. The silicon carbide materials, on the other hand, need temperatures of 1200°C or higher to obtain the final curing of the binder phase. At higher temperatures the binder is entirely transformed to silicon carbide and silicon nitride.

The basic lining concept used by Elkem is shown in Figure 3, which indicates the applications of some of the materials listed in Table II. Similar lining solutions are also used by other companies which Elkem Carbon supplies with carbon and silicon carbide materials.

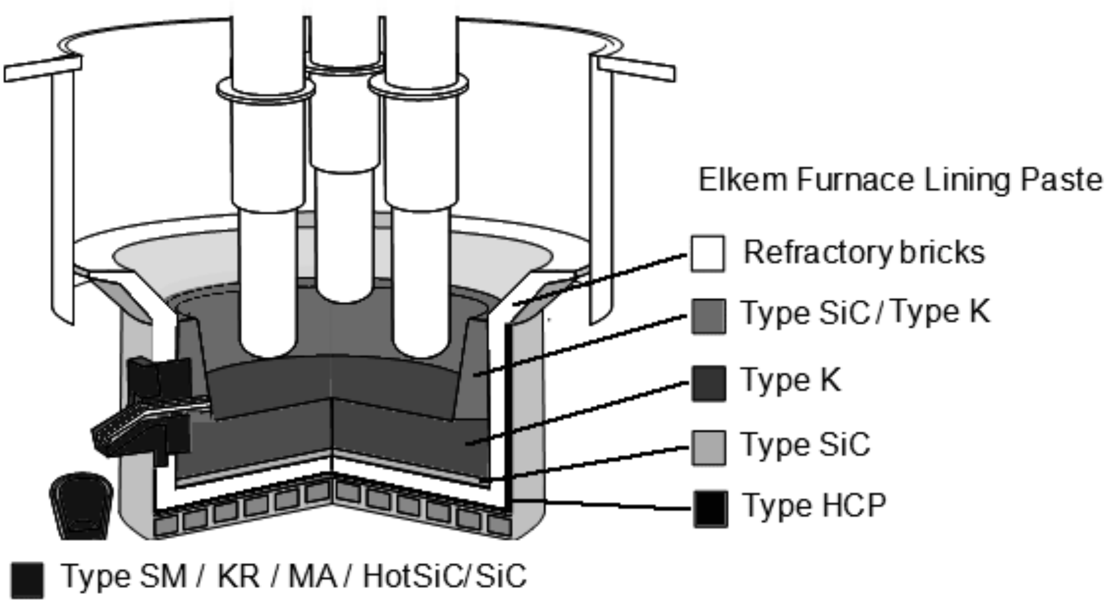

Figure 3. The basic lining concept for Elkem, indicating where different materials are used

Table II. Tap-hole lining products, main constituents, applications, and installation

Type	Installation	Application	Solid constituent	Binder
MA	Self flowing	Taphole	ECA	Pitch 65-90
C	Partly flowing	Taphole	ECA	Pitch 75-85
HotSiC	Self flowing	Taphole	SiC	Pitch 75-85
K30	Tamping	Bottom and side lining	ECA	Pitch 75
K	Tamping	Bottom and side lining	ECA	Cold binder
SM	Tamping	Tapping launder/spout	ECA	Cold binder
SiC	Tamping	Bottom and side lining Taphole/spout	ECA	Cold binder
KR	Tamping	Taphole/Spout	ECA	Resin
HCP	Tamping	Outer sidelining	Graphite	Resin
SiCR	Tamping	Ladles/spouts	SiC	Resin
EcoTap	Tamping	Tapping launder/spout	ECA	Environ- mental
Grout	Grouting	Side lining	SiC	Cold binder

Daily and weekly maintenance of tap-holes

The tap-hole channel should be refilled with a lining paste on a regularly basis. The tap-hole channel is normally closed with tap-hole clay between tappings, but it is important that this material, together with slag and metal, is removed periodically and replaced with a homogenous material. It is then important that the whole tap-hole channel is filled, but not overfilled, otherwise material may enter the furnace and constitute a barrier for the next tapping.

Furnaces with several tap-holes are easier to maintain than those with only one tap-hole. With several tap-holes the repair paste is allowed to heat up and finish curing before usage. In several countries furnaces are shut down for several hours each day during electricity demand peaks. This time is also available for tap-hole maintenance.

Major repair of tap-holes

The frequency of major tap-hole repair on a furnace will vary. Furnaces with all the tapping equipment in Table I will run for much longer periods without major repairs compared to furnaces with only oxygen lances as tapping equipment. The need for tap-hole maintenance would also be reduced if the furnace process is running well without a large amount of slag.

The furnace needs to be out of operation when a major tap-hole repair is carried out to avoid metal leakage. This should be combined with an annual maintenance shutdown of the furnace. The furnace should be drained well to avoid the risk of metal accumulating inside the furnace.

The quickest and best solution for the removal of old lining material is to use a large rock drill and a chisel hammer in combination, as shown in Figure 4. The rock drill is used to drill the area that requires repairing, and the chisel hammer to remove the intervening material. Excessive cracking in the surrounding lining can result if only a chisel hammer is used.

Figure 4. A large rock drill (left) being used to remove most of the old lining material from a damaged tap-hole, and the cleaned tap-hole before new material is installed (right). The thermal insulation plate protects workers from radiative heat, but is removed when new lining material is filled into the tapole

The addition of new material can start when sufficient old lining material has been removed and the opening vacuum-cleaned. The framework can be installed as shown in Figure 1, with a steel plate outside the tap-hole. This solution could be chosen when an ECA paste is used, although it does not lead to the 1200°C that the SiC paste needs for curing. Additional heating can be supplied by means of a gas burner or fire placed outside the steel plate if the temperatures in the repair paste do not reach 500°C.

The framework made of refractory bricks shown in Figure 5 is the preferred solution if a silicon carbide paste is used in the tap-hole. The bricks will maintain a higher temperature on the inside compared to the steel plate method. This results in better curing of the material, and the bricks will also prevent air from attacking the lining paste.

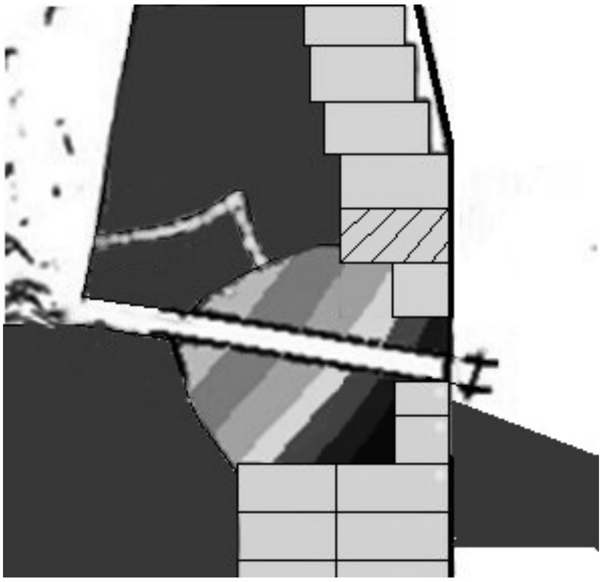

Figure 5. A repaired tap-hole where refractory bricks are used as formwork outside the repair. The refractory bricks prevent air from attacking the carbon or silicon carbide material

A tamping paste should be chosen if the temperatures are below 250°C. The paste is filled in layers that are tamped down to a height of 9 cm. The self-flowing paste has an advantage if there are a lot of cracks progressing inwards into the lining, and HotSiC is then a particularly good solution due its smaller grain size compared with ECA. During the repair of some older tap-holes, more than 2 t of HotSiC has penetrated into cracks around the tap-hole.

The maintenance frequency on larger tap-hole repairs has been reduced to one-third or less by the use of SiC pastes instead of carbon pastes. Problems with gassing from the tap-hole have also been reduced, together with tap-hole closure problems.

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