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METHODS OF ELIMINATING THE PHENOMENON OF LADLE NOZZLE CLOGGING

SPOSOBY ELIMINACJI ZJAWISKA ZARASTANIA WYLEWÓW KADZIOWYCH

A ladle nozzle is one of the slide gate ceramic elements. Systematic extension of the length of the steelmaking ladle campaign increases the demands on a ladle nozzle. The ideal solution would be a ladle nozzle which withstands the entire ladle campaign. In addition to thermal stability, ladle nozzles must be characterized by high resistance to corrosion and erosion caused by the flow of steel. An important factor affecting the durability of a ladle nozzle is clogging due to steel deoxidation products deposition in the nozzle channel. The phenomenon of clogging makes it difficult to regulate the rate of steel outflow from the ladle and, in extreme cases, can make the nozzle channel close. Clearing the nozzle by oxygen lancing accelerates its destruction.

The paper presents methods to prevent the phenomenon of nozzle channel clogging, from the simplest, based on the eutectic fluidization of inclusions in contact with the refractory material, to the most complicated, involving the formation of a buffer layer of inert gas between the ceramic material and the flowing metal. A solution based on a corundum material with an oxynitride matrix characterised by specific properties has also been presented.

Keywords: ladle nozzle, clogging, prevention methods

Wylew kadziowy jest jednym z elementów ceramicznych wchodzących w skład zamknięcia suwakowego. Systematyczne przedłużanie długości kampanii kadzi stalowniczej zwiększa wymagania stawiane kształtkom wylewowym. Idealnym rozwiązaniem byłby wylew wytrzymujący całą kampanię kadzi. Wylewy kadziowe muszą się charakteryzować, obok stabilności termicznej, wysoką odpornością na działanie korozyjne i erozyjne wywołane przepływem stali. Istotnym czynnikiem wpływającym na trwałość wylewu jest zarastanie w wyniku odkładania się w kanale wylewu produktów odtleniania stali. Zjawisko zarastania powoduje zaburzenie procesu regulacji szybkości wypływu stali z kadzi i w końcowym przypadku może spowodować zaślepienie kanału wylewu. Udrażnianie wylewu poprzez „przepalanie” za pomocą lancy tlenowej przyspiesza jego niszczenie.

W referacie przedstawiono sposoby zapobiegania zjawisku zarastania kanału wylewu kadziowego od najprostszego, wykorzystującego eutektyczne upłynnianie wtrąceń na styku z materiałem ogniotrwałym, do najbardziej skomplikowanego, polegającego na utworzeniu warstwy buforowej gazu obojętnego między tworzywem ceramicznym a przepływającym metalem. Przedstawiono również rozwiązanie wykorzystujące zastosowanie tworzywa korundowego z osnową tlenoazotkową o specyficznych własnościach.

1. Introduction

For steel deoxidation in the process of steel casting an aluminium or other elements which bond with oxygen and form high-melting oxides are applied. Deoxidation products deposit in the ladle nozzle channel. The build-up is composed of a non-metallic inclusions lattice with pure metal interlayers. The content of oxide phases in the build-up is low, reaching 5-15%.

Some of the first hypotheses attributed the clogging phenomenon to the chemical attack of reacting substances directly in the nozzle channel. It was found, how-

ever, that there were no conditions for an intense process of oxidation and clogging. At least 1 minute is needed for the formation of a permanent passage between contacting non-metallic inclusions [1]. However, there is no possibility of such long contact in a stream flowing through the nozzle. The movement of melt which surrounds the contacting oxide crystals would lead to their separation, preventing their tight bonding in the process of diffusion. Therefore, the formation of build-up composed of a lattice of high-melting oxides cannot result from the sintering of separated particles in the boundary layer. Such skeleton aggregates must form already in the

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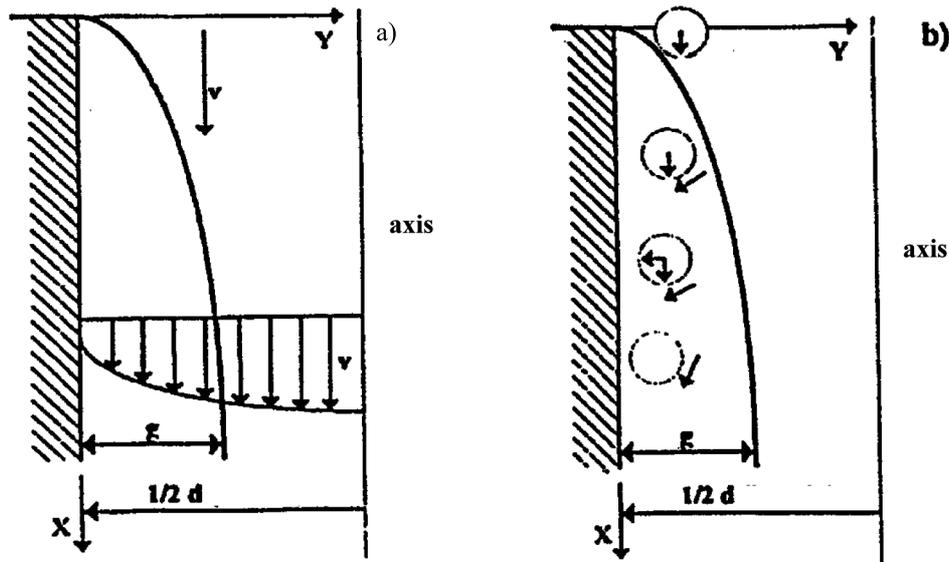


Fig. 1. A diagram of build-up formation on the nozzle channel surface(1) a) melt velocity distribution in the nozzle channel b) friction (braking) forces distribution in the melt layer g – dynamic boundary layer (build-up) thickness v – free metal stream velocity d – diameter of the channel

ladle. The investigations have confirmed the formation of skeleton non-oxide inclusions with metal streaks (inter-layers), the size of which reaches a maximum of $100 \mu\text{m}$. Moreover, it was found that the melting point of the metal carried away by the lattice of non-metallic inclusions is slightly higher than the surrounding melt as a result of reduced content of admixtures.

The metal flowing through the nozzle has different velocities. As the melt approaches the nozzle channel surface, its velocity decreases due to friction forces. It may be assumed that in the vicinity of the channel surface there is a parabolic velocity distribution (Fig. 1a). The occurrence of a velocity gradient on the boundary with the nozzle material induces tangential forces preventing the melt layer movement. These forces increase when approaching the refractory material- melt boundary. In consequence, the skeleton aggregate of a non-metallic inclusion in the contact area is affected by uneven forces. As a result of the slowing down of the lower part, it revolves and moves towards the boundary with the product surface (Fig. 1b). The pressing of inclusions against the nozzle channel surface by hydrodynamic forces leads to the formation of a metal layer reinforced with an oxide inclusions lattice. If the nozzle surface temperature is lower than the melting point of metal in the skeleton aggregate, the inclusions get “frozen to the wall”; otherwise, the skeleton structure disintegrates due to tangential forces. The inclusion structure decomposition and the washing out of the build-up are possible only in the case of inclusions fluidization in contact with the refractory material. It was estimated that in the process of steel killing when casting 100 t of steel, the

volume of build-up may reach 192cm^3 , which is sufficient to form a 5-cm high cork in the outlet opening having a 7-cm diameter.

2. Factors enabling the limitation of clogging

Considering the presented mechanism of nozzle clogging, it can be limited by:

1. increasing the melt temperature,
2. introduction of additives reducing the melting point of the non-metallic inclusions formed,
3. reducing the nozzle wettability by the melt,
4. eutectic fluidisation of inclusions in contact with the material,
5. formation of a buffer gaseous layer in the product-metal contact area.

The limitation of clogging by increasing the melt temperature is difficult to accept due to the method of running a metallurgical process, its economics and the negative effect on the durability of refractory lining, including the nozzle.

The introduction of a Ca-containing additive has certain limitations [2].

Reducing the nozzle wettability by the melt is also difficult to perform. Refractory materials angles of wetting by molten steel seldom exceed $120\text{-}140^\circ\text{C}$ and for this reason the decreasing of a contact layer this way is very limited. The introduction of a badly wetted graphite due to its high thermal conductivity coefficient contributes to the lowering of temperature on the liquid metal – product boundary, thereby increasing the tem-

perature gradient, and in consequence the flow velocity gradient.

There are also solutions which allow the formation of a buffer gaseous layer around the nozzle channel surface [3]. These are complicated solutions in terms of construction and materials. Other improvements to materials used in this case are aimed at limiting the amount of argon pumped and obtaining its more uniform outflow from the channel area.

The paper will present the results of using:

- nozzles made of materials the composition of which made it possible to fluidize the oxide-metallic aggregates in contact with the material,
- a combined system made up of a nozzle and ladle well enabling the formation of a buffer gaseous zone on the product – metal boundary,
- oxy-nitride bonding in a corundum material characterised by special properties.

3. Characteristics and results of applying the developed solutions

Two kinds of high-alumina materials have been prepared. In the first one, marked as “A”, the content of Al_2O_3 was reduced in relation to the standard product. A relatively homogenous raw material was used and a high level of product densification and its high resistance were ensured by selecting an appropriate size composition and binder (Table 1). Open porosity was below 14%, and compressive strength over 120 MPa. In the case of non-fired and chemically bonded material “B”, a granular additive was used to facilitate the fluidization of skeleton aggregates adhering to the nozzle channel walls

by reducing the melting point, and a chemical binder ensuring a relatively high mechanical strength was applied (Table 1).

Nozzles made of these materials, with a 50-mm channel diameter were used in one of the steelworks, in 60-t ladles. The temperature of cast steel ranged from 1600 to 1630°C.

It was found that in the case of both materials the clogging was limited and there was no need to lance the nozzles. In the case of nozzles made of a standard material the phenomenon of clogging was intense. Moreover, higher durability of nozzles was achieved. The maximum durability of standard nozzles was 24 melts, whereas for the newly developed nozzles it ranged from 25 to 41. The conducted trials showed that the additive introduced in material “B” did not cause the washing out or enlarging of the nozzle channel. Microstructural observations of nozzles after service confirmed the effectiveness of the adopted method of nozzle clogging limitation (Fig. 2).

The concept of forming a buffer gaseous layer on the product – metal contact in order to limit the process of nozzle clogging was presented a few years ago by the Japanese [4, 5]. This solution involves using a porous, gas-permeable nozzle block through which a neutral gas is blown. Particular attention was given to the influence exerted by the homogeneity and uniform pore distribution in a material on the uniform outflow of gas from the nozzle channel surface. Due to considerable differences in pore diameters, the gas flowing at low velocity passes through wider pores, where it encounters less resistance, leaving the pores with small diameters inactive. As an example, a diagram of gas flow through a gas-permeable material has been shown in Fig. 3.

TABLE 1

Basic properties of nozzles and operating test results

Type of material	Open porosity %	Apparent density g/cm^3	Compressive strength, MPa	Al_2O_3 content Main component	Durability (number of melts)	Working conditions
S (fired)	17,9	2,76	37,9	min. 80% corundum mullite	max 24 (clogging)	Temp. 1600-1630°C ladle capacity 60 t
A (fired)	13,8	2,59	127	64% Mullite	25-40 (without clogging)	
B (non-fired)	18,7	2,70	36	74% corundum mullite	26-41 (without clogging)	

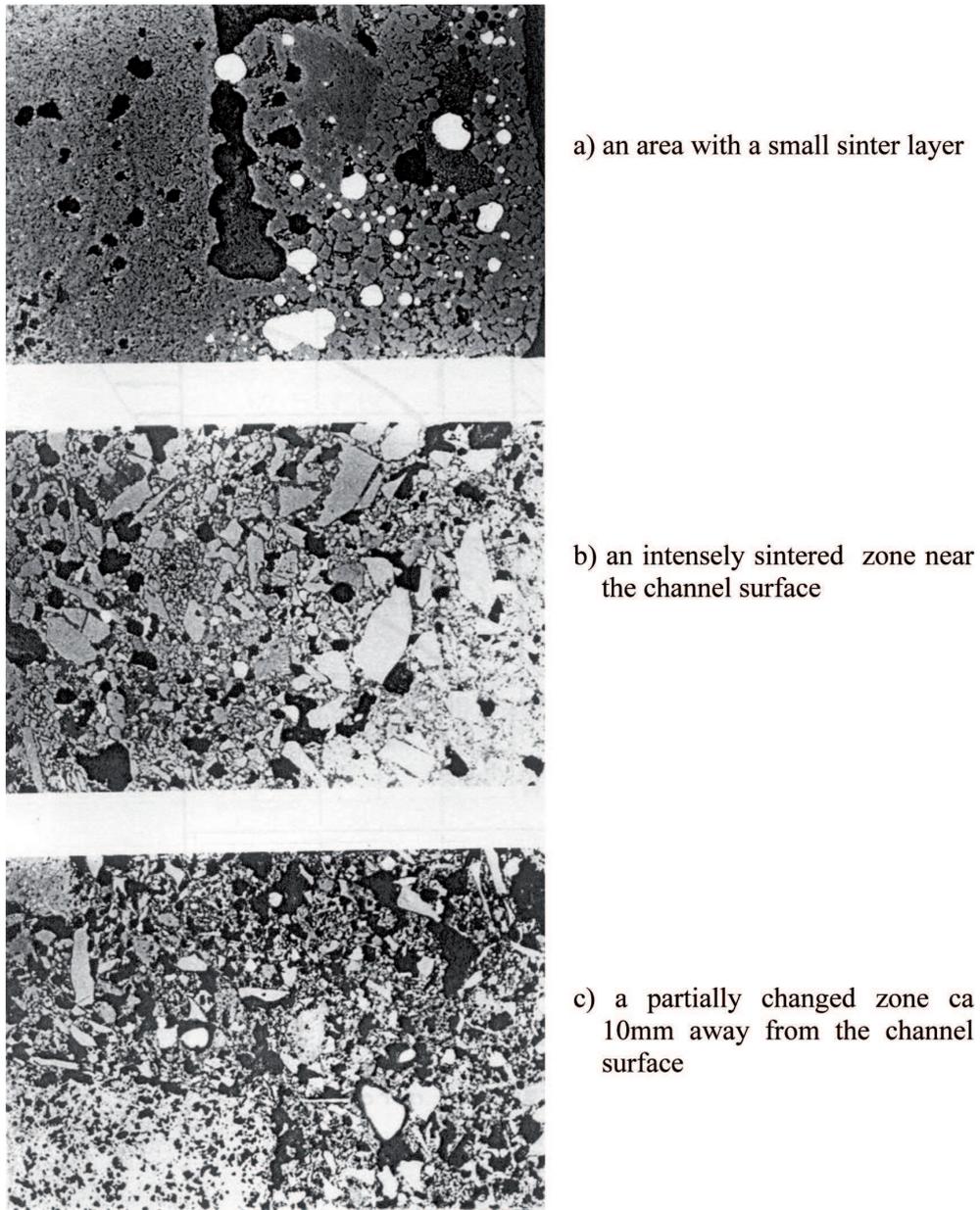


Fig. 2. The microstructure of nozzle "B" after service

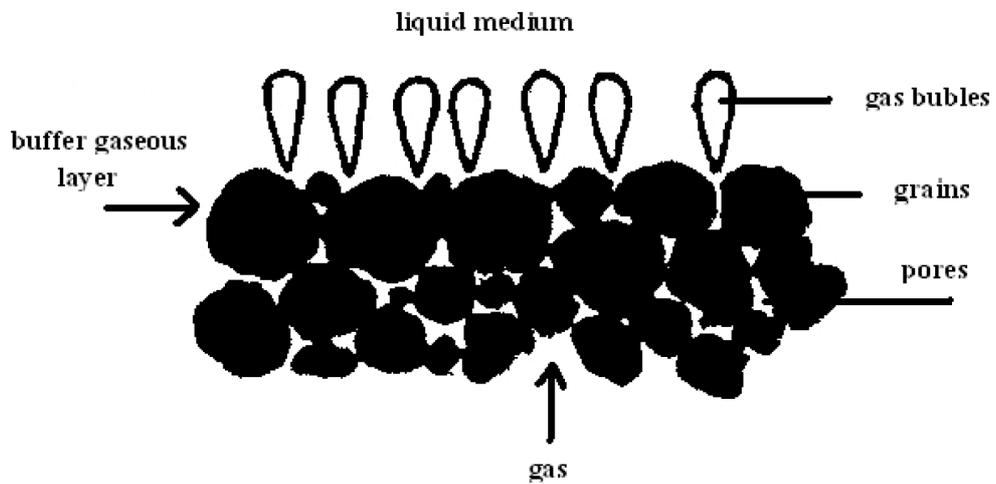


Fig. 3. A diagram of gas flow through a gas-permeable material

An analysis of the above solution revealed that beside the undeniable effect of nozzle clogging limitation, it may also bring other advantages, which are important in the absence of a typical clogging process. The fact of limiting the contact between the metal and nozzle channel surface, and in particular the reduction of metal penetration into the material pores in the process of argon pumping through these pores may limit corrosion. The porous texture of products enables compensation of stresses caused by the existence of a temperature gradient in the block, which results from sudden heating of the block at the moment of starting the tap, or at the moment of its cooling, so in general it should positively influence the resistance to thermal shocks. Based on the above concept, a combined system has been developed, consisting of a ladle well with a channel that supplies gas to the nozzle and a gas-permeable nozzle itself [6]. The combined system manufacture required:

1. developing a gas-permeable nozzle material characterised by high mechanical strength,
2. developing a ladle well material ensuring its durability throughout the ladle campaign.
3. developing the construction of particular elements and the manner of their joining which ensure stabilized gas flow conditions – Fig. 4 and 5, limitation of defects in the process of manufacture and assembly, and in particular, limitation of uncontrolled gas leak during operation.
4. taking into consideration a construction which enables nozzle replacement.

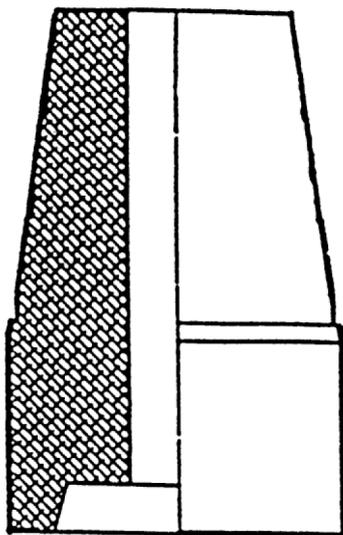


Fig. 4. A gas-permeable ladle nozzle

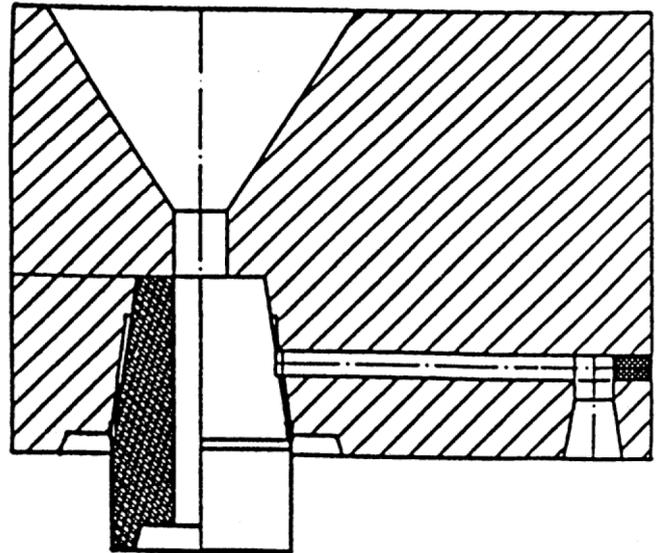


Fig. 5. The combined system

The investigations into a gas-permeable material for nozzles were based on a separated grain monofraction of the selected corundum material with a 94% content of Al_2O_3 . A mass grain curve was selected so as to obtain a refractory material characterized by the assumed physical parameters, i.e. appropriate pore size distribution for pores having the average size of $30 \mu m$ and simultaneous high mechanical strength in the order of 50 MPa, which guarantees the nozzle durability during the replacement of the slide gate upper plate. The examined velocities of air flow through ladle nozzles, at the pre-defined pressure of 0.10 MPa showed the repeatability of the material properties. The flow was 40-45 l/min, while the flow through the combined system under the same pressure conditions reached more than 35 l/min. Operating tests were conducted in one of the steelworks on a continuous steel cast line. The combined system was installed in the main steel casting ladle – specially adjusted to the new solution – instead of the standard slide gate of the ladle. The testing conditions were as follows:

- ladle capacity – 70 tons,
- casting temperature – $1570-1620^{\circ}C$,
- casting times – 60-100 minutes (one melt),
- steel grades – 25G2, ST36, 18G2B, RST372, 34GS, 38GL, C21, S235JRG2, R35.

In the first phase of casting, argon was supplied to the combined system at the pressure of 0.2 MPa, next the pressure was reduced. The durability of nozzles was 7 to 13 melts, which gives a total time of casting by 1 nozzle ranging from 533 to 1054 min. (8 hours 53 minutes to 17 hours 34 min.). Four combined systems were tested and found to cause no disturbances in the casting processes. It was found that the ladle nozzle durability increased on average from 5 to 10 melts per ladle. In the conditions of

the system application there was a possibility to further optimize the flow of argon, which could have resulted in the extension of average nozzle durability.

An interesting material solution for the ladle nozzle, developed by authors, is a corundum material with sialon bonding [7]. Sialon ceramics, initially used mainly to obtain compact constructional materials, relatively recently have been used on a higher scale as components of refractory materials. This is due to the benefits resulting from high thermo-mechanical properties, increased abrasive resistance, as well as higher resistance to oxidation than traditional oxide materials containing carbon or carbides. Sialon-bonded corundum materials have been applied in the production of previously developed ceramic slide gate elements, which were used in one of the steel plants. The properties of ladle nozzles obtained as a result of investigations have been presented in Table 2.

TABLE 2

Quality properties of a ladle nozzle made of sialon-bonded corundum material

Indicator	Measuring unit	Indicator value
Open porosity	%	16-19
Apparent density	g/cm^3	2,87-3,03
Compressive strength	MPa	120-200
Bending strength at 20°C	MPa	23,2
Bending strength at 1450°C	MPa	26,9
Total creep at 1600°C under the load of 2 N TSR (1000°C-water)	%/h number of changes	-0,027 over 30
β sialon content	%	19-21

The results of operating tests conducted in two steelworks confirmed the high quality of nozzles compared to the ones made of mullite-bonded corundum. The corundum-sialon material each time withstood the whole ladle campaigns of the 40 and 70 t ladles showing slight signs of corrosion. The slag zone, as revealed by microstructural observations, in the form of a non-continuous layer reached the maximum of 0.9 mm, whereas the reaction zone, in which matrix components in the form of SiAlON were reactively changed into the glassy phase, with beads of Si or FeSi inclusions which impregnate the material, had a dense structure and reduced porosity. In all the examined zones the observed changes occur in layers, parallel to the working surface. In the transition there is a porous layer related to SiAlON decomposition, and next a compact layer resulting from the presence of reactively formed AlN or Si₃N₄ recrystallization (AlN was probably formed as a result of SiAlON decomposition in the porous layer and crystallized in the cool zone, whereas volatile SiO was bound in the silicate phase of the reduction layer, contacting the porous

layer of the partially altered product zone). These layers are better developed in the matrix than in ceramic skeleton areas, which indicates that in this part of the material the processes of transformation under working conditions occur mainly in the matrix (Fig. 6, 7, 8).

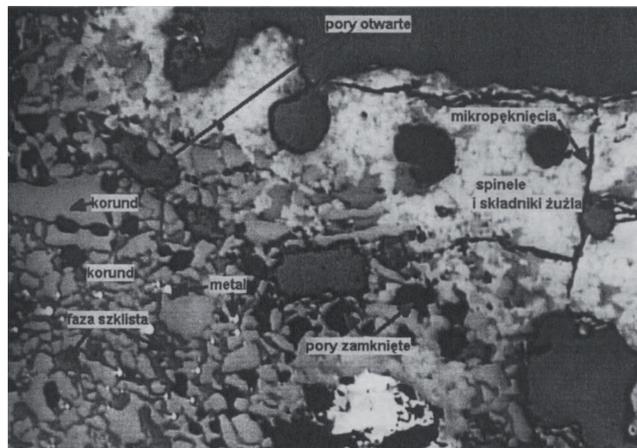


Fig. 6. The microstructure of the slag zone contacting the reaction layer of the transformed nozzle after service

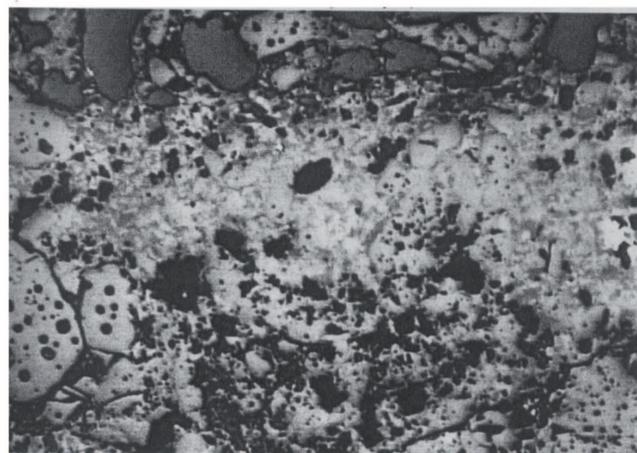


Fig. 7. The microstructure of the transition zone – porous and compact layer

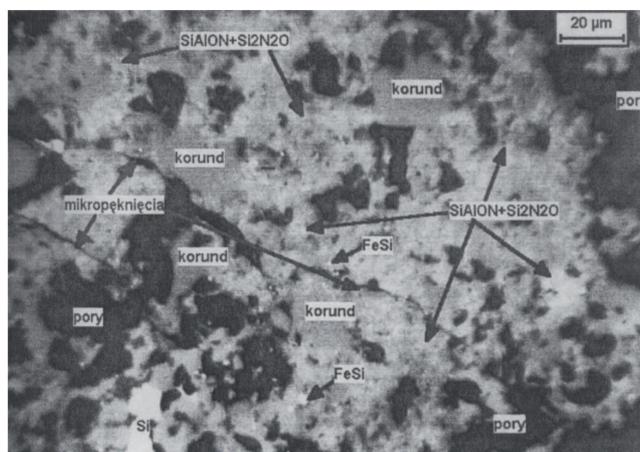


Fig. 8. The microstructure of a corundum-sialon nozzle after service – the unaltered product zone

Most probably this direction of sialon-bonded corundum materials development will be followed by an increasing number of different users of refractory ceramics, not only the metallurgical industry.

4. Conclusions

The conducted investigations confirmed the possibility of limiting the process of ladle nozzle clogging by controlling the composition and microstructure of materials they are made of, and allowed constructional changes to be worked out.

The beneficial results were obtained by using:

1. ladle nozzles characterised by limited channel clogging owing to the selection of a raw material composition enabling the fluidization of the build-up in the channel,
2. a combined system (ladle well with a ladle nozzle), in which a protective buffer layer of gaseous argon was obtained between the internal surface of nozzle and the flowing steel through appropriate selection of grain composition and constructional changes,
3. a ladle nozzle with an extended life owing to the use of sialon-bonded corundum materials.

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