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REFINING OF LIQUID STEEL IN A TUNDISH USING THE METHOD OF FILTRATION DURING ITS CASTING IN THE CC MACHINE

RAFINACJA CIEKŁEJ STALI W KADZI POŚREDNIEJ METODĄ FILTRACJI PODCZAS JEJ ODLEWANIA NA URZĄDZENIU COS

Hitherto existing investigations concerning the ceramic filter use in the steel making processes (both of laboratory and industrial scale) have given good results. The obtained results of filtration (in the industrial) have proved that this method may be used as an effective and cheap way of steel filtration from non-metallic inclusions. Placing filters in the tundish is the best location in consideration of limiting the possibility of secondary pollution of steel. Yet, the results presented in this paper, of an experiment prepared and carried out in the industrial environment, are the only positive results obtained, which are connected with so much quantities of liquid steel processed with use of the multi-hole ceramic filters.
Keywords: steel, refining, ceramic filter, solid non-metallic inclusions, tundish, continuous casting

Dotychczasowe wyniki badań procesu filtracji stali przy pomocy wielootworowych filtrów ceramicznych (zarówno w skali laboratoryjnej jak i przemysłowej) dały pozytywne rezultaty. Uzyskane wyniki badań procesu filtracji (w warunkach przemysłowych) wykazały, że metoda ta może być skutecznym i tanim sposobem usuwania ze stali wtrąceń niemetalicznych. Lokalizacja filtrów wielootworowych na drodze technologicznej wytwarzania stali najkorzystniej sytuuje się w miejscu przegród przelewowych w kadzi pośredniej urządzenia COS. Prezentowane w pracy wyniki eksperymentu przygotowanego i przeprowadzonego w warunkach przemysłowych są jak do tej pory jedynymi, zakończonymi pozytywnie, podczas których procesowi rafinacji przy pomocy wielootworowych filtrów ceramicznych poddano tak duże ilości ciekłej stali.

1. Introduction

Researches being carried out nowadays on metallurgical processes of steel making are focused on the final process stages due to the necessity to gain the high quality and high performance steel products in a cost-effective manner. Numerous works are being carried out in this area, which are primarily concerned with:

- investigations of the hydro-dynamics of steel flow and steel blending within the system of the main ladle – tundish – CC machine's crystallizer,
- investigations of the liquid steel refining in the tundish of the CC machine.

It is evident from the hitherto existing experience [1, 2] that the conventional out-of-furnace steel treatment (especially that which is deoxidized by depositing, e.g. with use of aluminium) does not ensure high levels of the metallurgical purity. Furthermore, the presence in liquid steel of non-metallic inclusions of Al_2O_3 type throws into confusion the process of continuous casting due to the phenomenon of covering the ladle discharge nozzles by a layer of such inclusions. According to judgements presented by many research centres [3-6] the steel filtration with use of multi-hole ceramic filters can be the efficient and cost-effective method of removing the non-metallic inclusions from liquid steel. The experimental results obtained hitherto in the laboratory and field indicate the substantial reduction in content of non-metallic inclusions and damaging impurities in liquid steel [7-14]. Differences, however, exist in levels of efficiency of this steel refining method, depending on local filtration conditions. The reason for such differences can be found in the phenomenon of secondary oxidation of liquid steel by the atmospheric oxygen [4, 5, 7]. The positive results obtained in the laboratory-scale research have bcecome the base to undertake the trials to filtrate liquid steel in industrial conditions. A series of model investigations has been carried out, and then, after obtaining the positive results, a series of industrial-scale melts of steel has been produced [8]. The goal of the research carried out, the results of which are presented here, has been to prove the possible extent of the solid non-metallic inclusion removal from liquid steel through the steel filtration by means of multi-hole ceramic filters. These inclusions most frequently throw into confusion the process of continuous casting d inclusion deposits formed on the walls of the submersion-type nozzles, which gradually reduce the nozzle cross-section (which cause nozzle accretion). The aim of the research carried out has been to prove

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that the liquid steel filtration is a cheap and efficient additional processing stage, separating the non-metallic inclusions, which in case of the conventional casting technology could remain in the cast steel bodies.

2. Results of model investigations of the process of steel filtration in the tundish of CC machine

It is assumed in the theoretical considerations that in the process of filtration of non-metallic inclusions from liquid steel by means of multi-holeceramic filters, the internal surface of the filter orifice is the „filtrating" surface. Soskov [15], taking into account the above mentioned dependencies, has proposed a simplified mechanism of filtration of non-metallic inclusions from liquid steel, comprising three stages:

- transportation of the non-metallic inclusion to the separating surface between liquid steel and ceramic filter material,
- passage of the non-metallic inclusion through the interphase borderline separating liquid steel from ceramic filter material,
- stop of the non-metallic inclusion on the ceramic filter filtrating surface.

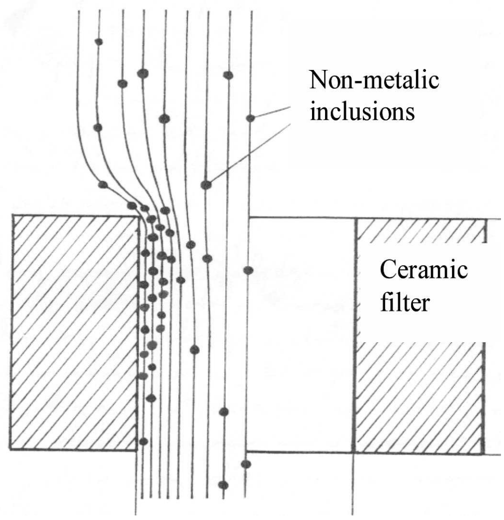


Fig. 1. Distribution of current lines in the liquid stream

It is difficult to indicate explicitly which of the above mentioned stages of such a mechanism of liquid steel filtration is responsible for the control over the filtrating process. In case of the laminar flow of steel through the filter orifices only the small part of non-metallic inclusions (located in the outermost layer of the steel stream) is able to reach contact with the interphase borderline between liquid steel and ceramic filter material, what can be seen in Fig. 1. Instead in case of the turbulent flow there is a much higher likelihood of reaching contact with this borderline by the non-metallic inclusion. The process of passage of the non-metallic inclusion through the borderline between liquid steel and ceramic filter material is determined by the surface properties of contacting three phases (liquid steel – non-metallic inclusion – ceramic filter material). At the same time the probability of a non-metallic inclusion stop at the filtrating surface of the filter is by no means the function of many factors, including the process parameters of steel filtration (steel temperature and velocity of steel flow through the filter orifices) and the filter structural characteristics, and, first of all, the chemical composition and physical state of non-metallic inclusions: different ways of the non-metallic inclusion stop and differentiated efficiencies of the liquid steel filtration should be expected in case of solid and liquid non-metallic inclusions, the products of steel deoxidation by depositing. It is suggested here to assess the probability of the non-metallic inclusion stop at the filter surface in the flowing steel environment as based on the value of work of the inclusion adhesion to the ceramic filter material, which can be expressed by formula (1):

$$W_{A(LS)}^{F-NMI} = W_{A(g)}^{F-NMI} - \sigma_{LS}(\cos Q_{F-LS} + \cos Q_{NMI-LS}) \quad (1)$$

where: $W_{A(g)}^{F-NMI}$ is the work of adhesion of a non-metallic inclusion and the ceramic filter material in atmospheric environment, mN/m,

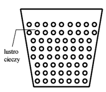
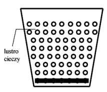
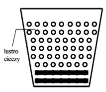
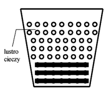
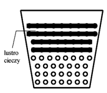
Q_{F-LS} is the wetting angle of ceramic filter material in liquid steel, °,

Q_{NMI-LS} is the wetting angle of non-metallic inclusion in liquid steel, °,

σ_{LS} is the surface tension of liquid steel, mN/m.

TABLE 1

Configuration filter holes in the model of multi-hole filter

Variant	In the total filter surface, %	Scheme of the filter model
a	16,16	
b	14,06	
c	11,97	
d	9,87	
e	8,68	

It is not strictly evident from the formula (1) which of the physical states of the inclusion it refers to. In theory the adhesion phenomenon also exists between two solid phases, but it is however of insignificant importance in respect to the solid non-metallic inclusions in the environment of liquid steel filtration (spherical form, flat filtrating surface of the filter).

In order to determine an optimal location of ceramic filters within the tundish, with the point of view of the effectiveness of steel filtration under the most suitable hydro-dynamic parameters of steel flow, the model research has been carried out in the Metallurgical Department of the Silesian Technical University, of the hydro-dynamic phenomena occurring in the tundish provided with the multi-hole filters [8]. According to the rules of the similarity theory the tundish model has been made together with the model of multi-hole filter, performing also a function of the overflow partition. The orifice diameter and orifice number have been selected in a way to obtain minimum flow resistance. The total surface of the orifices, through which the liquid flows, has been assumed as 12.86% of the total surface of the partition. However, because of the level of the model liquid in the tundish, the working filter surface has been separated, in which the total surface has increased to 16.16% of the filter working surface. Research has been carried out in such a way that there have been in use different configurations of the filtrating orifices, obtained through plugging successively the next row of orifices above the ladle bottom. In such instances the total surface of the filtrating orifices has amounted correspondingly: 14.06% (variant b), 11.97% (variant c) and 9.87% (variant d) of the filter working surface. In the final variant only four rows of filtrating orifices have been opened above the ladle bottom, which have constituted 8,68% (variant e) of the filter working surface. The geometrical configurations of orifices in the filter model, used in the research process, are presented in table 1. The model research of steel flow through the tundish provided with the multi-holefilters has consisted in introducing to the CC machine model the well fitted quantity of water as the model liquid, and stabilizing the system by means of control of the velocity of the liquid flow through the model at the required level. Then the water solution of $KMnO_4$, as a dying agent, has been added to the liquid. The measurements carried out have referred to its concentration in the time at each nozzle. Several measurement series have been carried out for different geometrical configurations (variants) of the filtrating orifice location. Additionally the experiment progress has been recorded with video camera, what has allowed to visualize the phenomena of the liquid flow through the filter and liquid mixing in the tundish model (Fig. 2). The dynamic characteristics have been determined through registration of the dying agent concentration variations in time in response to a step function excitation during the liquid flow through the tundish model. The results obtained during the model research have been further transformed mathematically by means of the developed computer software. In such way there has been obtained the mathematical models of liquid flow for each of the geometrical configurations of filtrating orifices, as well as the time-constants, which characterize the times needed by the dying agent to reach the tundish nozzle and the dynamics of liquid mixing in the ladle [8]. The authors [16] are now also occupied with analysing the possibility of use the multi-hole ceramic filters in other models of the tundish.

Fig. 2. Model investigations of the filtration process

3. The hitherto obtained results of the research of liquid steel filtration in the industrial environment

Xintian et al. [13] presents the results of trials of industrial investigations of the process of filtration of low-carbon steel in the continuous casting environment by means of filters based on corundum (Al_2O_3), quartz and corundum ($Al_2O_3 \cdot SiO_2$) and limestone (CaO). The filters in form of panels 150 mm thick with the filtrating orifices 50 mm in diameter have been placed in the tundish of CC machine. The filters, prior to start the steel casting, have been preheated to the temperature of 800-1000°C (1073-1273 K). The following quantities of steel have been casted during the experiment: 280 Mg through the corundum filter, 350 Mg through the quartz and corundum filter and 350 Mg through the limestone filter, each at the velocity of 0,8-1,05 m/min and to the flat ingot moulds of (210-250)×1300 mm cross-section. The effectiveness of the process of filtration has been determined as variation in the average relative content of non-metallic inclusions in samples of liquid steel collected in the tundish upstream and downstream of the filter. The best results have been obtained for the corundum filter, for which a reduction in the total relative content of non-metallic inclusions (η_{MeO}) has amounted 63.63% (49.26% of Al_2O_3 inclusions and 41.17% of SiO_2 inclusions). The steel filtration with use of limestone filters has been of lower effectiveness: the total relative content of non-metallic inclusions has decreased in the best instance only 42.11% with, at the same time, highest decrease in SiO_2 inclusions of 83.68%. It is worth to pay attention to the investigation of the process of filtration of the low-carbon liquid steel (C⩽0,12%) carried out in the industrial environment of the converter plant of the Metallurgical Works in Novolipetsk, Russia (Novolipetsk Steel) [17]. The sieve filter made of corundum has been placed in one of the partition of the tundish of 22 Mg capacity of the dual channel CC machine. The number and dimensions of the filtrating orifices have been differentiated so (diameters 7,20 and 40 mm and lengths of 40, 150 and 200 mm) that the wide range of filtrating surfaces has been obtained. Prior to start the steel casting the filters (partition) have been preheated to the temperature of 1000-1100°C (1273-1373 K). The steel casting velocity during the investigations carried out, has amounted 0,8-1,2 m/min. In liquid steel samples (collected in the tundish) the decrease has been stated in oxygen content of 23 and 34%, while in the samples collected from the concast slabs (experimental slabs and comparative ones) the non-metallic inclusion content has been analysed. In each instance the content of non-metallic inclusions has been of lower value for the filtrated steel. There has been stated that clear correlation exists between the decrease in inclusion content $\eta_{[MeO]}$ and the filtrating surface of the filters used: the higher the value of the filtrating surface the greater the increase in quantity of non-metallic inclusions removed from the steel.

Mancini J. and Stel J. [18] have presented the results their industrial investigations of the process of filtration of liquid steel, which correlate to the most extent with our methods presented here. It comprises the method of filter installation in the tundish, as well as assessment of steel pollution with solid non-metallic inclusions. However the lack of adequate preheating of the tundish with the ceramic filter installed has led to the result that most of trials have been terminated unsuccessfully (the filters have broken).

The results of industrial research recently presented by Bulkowski, and others [19]. However, it is difficult to relate to them because they were cast only one melting capacity of 30 Mg.

4. Results of industrial investigations of steel filtration

The hitherto obtained results of the laboratory researches of liquid steel filtration by means of ceramic filters [9, 10, 14] have become the base for preparation and implementation of the industrial application of the steel filtration process in the processing line of the continuous casting machine. Based on the results of research presented in literature [13, 17 and 18] a trial has been undertaken to verify the results reported. The experiments have been prepared and then carried out in the steel plant of one of the Metallurgical Works belonging to the Polish Steel Plants (now ArcellorMittal Steel). Unlike the experiments, which results are presented in the articles [13, 17 and 18] the filtration has been carried out with unequally larger quantities of liquid steel. The weight of one melt has been of 330 Mg and the casting sequences have comprised from three to six melts. Steel has been casted into rectangular ingot moulds of 280×300 and 280×400 mm cross-sections. The steel casting velocity has amounted 0,5-0,8 m/min. Fig. 3 presents the trough-type tundish prepared, in which a ceramic filter has been mounted. The filter used, in form of a barrier, has been made with 26 orifices of 60 mm diameter and filtrating surface of 808236 mm^2 (Fig. 4). The filtrating orifices have been of 165 mm in length.

Fig. 3. Tundish of the CC machine provided with the ceramic filter

The filter has been manufactured by Alcor S.A. company of Krzeszowice, Poland, and has been made of mullite-based body. According to the term of **the multi-hole ceramic filter slenderness ratio**, proposed and brought into use by the author of this paper, calculated as a quotient of the filtrating orifice (channel) height – (length) by the orifice (channel) width (λ = h/d), the filter used in the experiment has been of slenderness ratio λ = **3,10** [20]. Ten (10) melts of A700 steel (rail steel), about 330 Mg each, have been in a sequential manner casted during the first trial of industrial steel filtration.

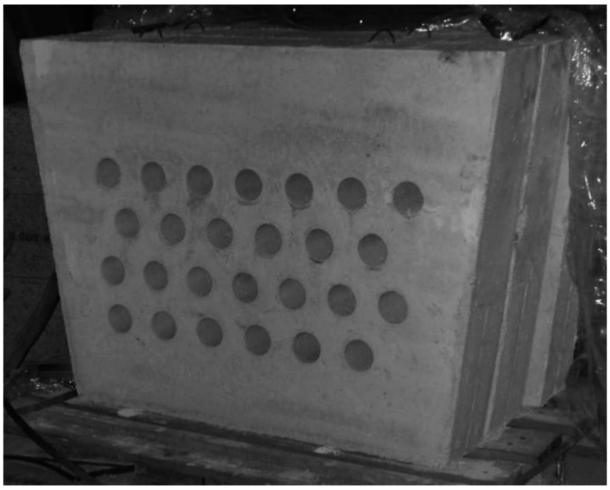


Fig. 4. Multi- hole ceramic filter

After termination of the steel casting sequence the „wash-out" effect has been discovered in the filter central part. The initial assessment of the macroscopic structure of the continuous castings of the filtrated steel (not including the investigation of steel contamination with non-metallic inclusions) has proved good product quality. The first carried out industrial trial of steel filtration in the tundish of CC machine has not thrown the continuous casting process into any confusion and not proved the earlier apprehension of emergency risk. The second trial of industrial steel filtration, in the tundish of CC machine, comprise a sequence of three melts of 34 GJ steel, about 330 Mg in weight each. During the filtration process the samples of filtrated steel have been collected from one half of the ladle, while from the second, non-filtrated one the samples have been collected for analysis of total oxygen content. Results of the investigations carried out are presented in graphical form in Fig. 5 and 6. Prior to start of the steel casting process the multi-hole ceramic filters installed has been pre-heated together with the tundish to the temperature of 1250°C (1523 K).

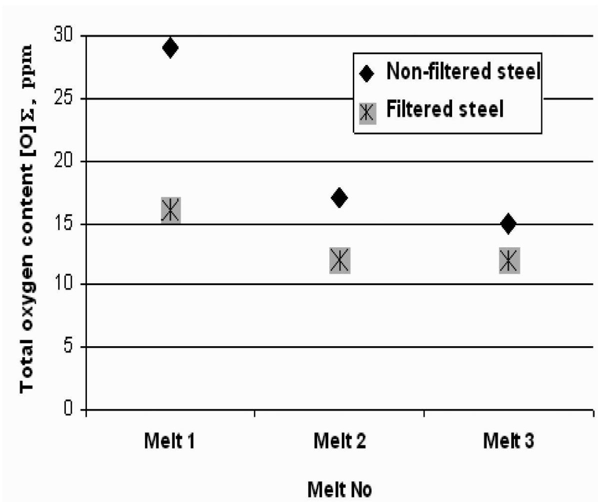


Fig. 5. $[O]_T$ total oxygen content variation in each of the melt sequence (second trial) – 34GJ steel

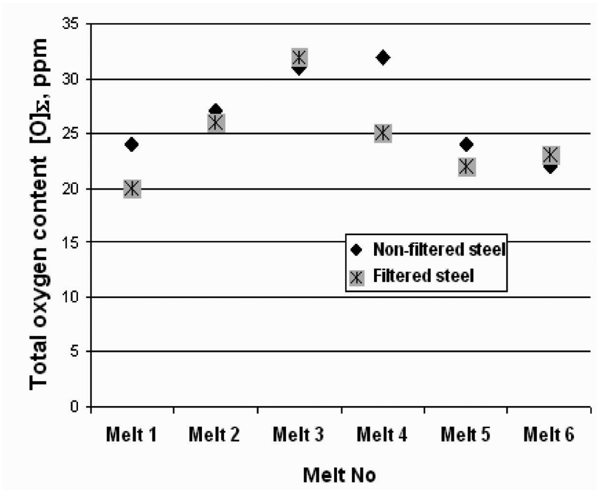


Fig. 6. $[O]_T$ total oxygen content variation in each of the melt sequence (third trial) – SE03 steel

The third trial of steel filtration in industrial environment, in the tundish of CC machine, has also comprised a sequence of six melts of SE03 steel, each 330 Mg in weight. Similarly as previously, during the third trial the samples have been collected, at the filtrated and non-filtrated steel side, for oxygen content analysis. The results of the investigations carried out are presented in graphical form in Fig. 7 and 8.

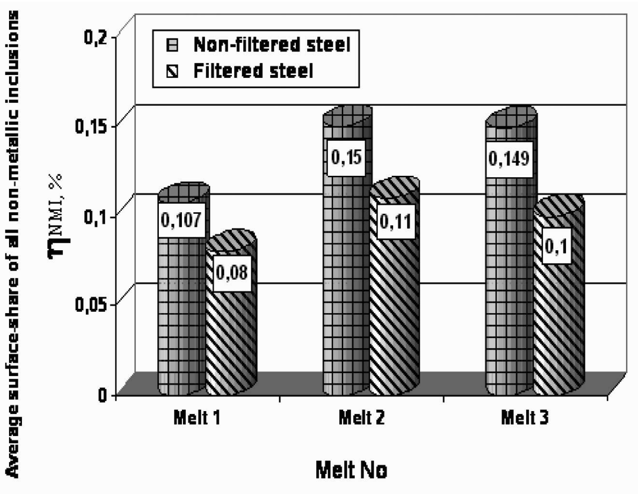


Fig. 7. The effectiveness of removing non-metallic inclusions as measured with the average rate of non-metallic inclusion superficial share NMI – 34GJ steel

The chemical composition of samples of filtrated and non-filtrated steel has been determined with the emission spectroscopy method combined with spark excitation. Total oxygen content has been evaluated with a combustion method used in Leco's analyzer. The non-metallic inclusion content (surface-shares) and their dimensions have been determined with Leica's computerized image analyzer Leica Q500 MC on samples in the form of polished microsections zoomed 500 times. The inclusions have been investigated for one hundred of randomly selected fields of every sample (a single field of observation has been of 20577,6 μm^2 in size). When determining the inclusion percentage, i.e. the area occupied by the inclusions in the surface of the observed microsection, the „area" option (expressed in μm^2) has been used, while the so called Feret's diameter option (expressed in μm) has been used for inclusion number determination. In the analyses of steel contamination with non-metallic inclusions, the so-called factor of surface-share variation and of the inclusions number has been used, which is defined as:

$$\eta_{NMI} = \frac{x_p - x_a}{x_p} \cdot 100\,\% \tag{2}$$

where: x_p – surface-share of the inclusion (or the number of inclusion) prior to filtration,

x_a – surface-share of the inclusion (or the number of inclusion) after filtration,

for the following intervals of the inclusion diameters according to Feret: 0,5-2,5 μm, 2,6-6,5 μm, 6,6-15 μm. The border of phase division between filter ceramics and solidified steel together with adjoining areas (after polishing the sample surface and deposition of thin film of gold) has been examined with the X-ray microanalyses method by means of Noran Instrument's Hitachi S-3500N scanning microscope.

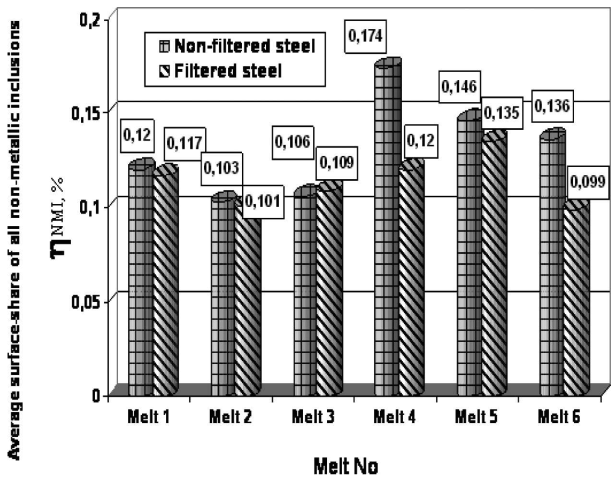


Fig. 8. The effectiveness of removing non-metallic inclusions as measured with the average rate of non-metallic inclusion superficial share NMI – SE03 steel

The investigation results of the chemical composition and the filtrated and non-filtrated steel contamination are listed in Tables 2, 3 and 4. In each experimental melt the change in steel chemical composition has been stated during filtration (see Table 2). In a lesser degree it applies to carbon, manganese and silicon, and in substantially greater degree it applies to sulphur, aluminium and total oxygen. Inconsiderable loss of carbon, manganese and silicon can result from steel re-oxidisation by the atmospheric oxygen. But substantial loss in total oxygen, aluminium and sulphur is most certainly the result of the steel filtration of non-metallic inclusions (simple oxides, complex oxides and oxysulphides).

The inclusions observed have differed in shape and size. In the aluminium deoxidized melts (the second trial and the third trial) the single inclusions as well as irregular in shape the inclusions clusters of different configuration have been observed. They consist of Al_2O_3 non-metallic phase, being the product of the deoxidizing process.

TABLE 2

Chemical composition of filtrated and non-filtrated steel

Test No	Symbol of the melt	Chemical composition steel: carbon, [C] %	η_C, %	manganese, [Mn] %	η_{Mn}, %	silicium, [Si] %	η_{Si}, %	phosphorus, [P] %	η_P, %	sulphur, [S] %	η_S, %	aluminium, $[Al]_{total}$ %	η_{Al}, %	oxygen, $[O]_{total}$ ppm	η_O, %
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	M-1	0.340/0.337	**0.88**	0.840/0.839	**0.12**	0.250/0.210	**16.00**	0.025/0.024	**4.00**	0.020/0.020	**00.00**	0.0040/0.0039	**2.50**	29.0/16.0	**44.83**
	M-2	0.350/0.337	**3.71**	0.800/0.800	**0.0**	0.210/0.210	**0.00**	0.012/0.011	**10.0**	0.017/0.015	**11.76**	0.043/0.036	**16.23**	17.0/12.0	**29.41**
	M-3	0.370/0.360	**2.70**	0.840/0.820	**2.40**	0.230/0.200	**13.04**	0.009/0.009	**0.00**	0.018/0.017	**5.55**	0.047/0.034	**27,60**	15.0/12.0	**20.00**
3	M-1	0.140/0.138	**1.43**	0.780/0.720	**7.69**	0.190/0.185	**2.63**	0.013/0.013	**0.00**	0.011/0.010	**10.00**	0.038/0.032	**15.79**	24.0/20.0	**16.66**
	M-2	0.142/0.139	**2.11**	0.770/0.760	**1.30**	0.191/0.188	**1.57**	0.0195/0.0165	**15.38**	0.017/0.017	**0.00**	0.042/0.033	**21.43**	27.0/26.0	**3.70**
	M-3	0.140/0.140	**0.00**	0.769/0.760	**1.17**	0.200/0.193	**3.50**	0.011/0.009	**18.10**	0.0135/0.0120	**11.11**	0.034/0.024	**29.41**	31.0/34.0	**-9.67**
	M-4	0.139/0.138	**0.17**	0.775/0.748	**3.48**	0.198/0.185	**6.56**	0.013/0.012	**12.50**	0.0110/0.0105	**4.54**	0.039/0.027	**30.77**	32.0/25.0	**21.87**
	M-5	0.151/0.145	**3.97**	0.759/0.731	**3.69**	0.184/0.183	**0.54**	0.012/0.011	**8.33**	0.016/0.014	**12.5**	0.041/0.037	**9.76**	24.0/22.0	**8.33**
	M-6	0.150/0.147	**2.00**	0.740/0.740	**0.00**	0.210/0.197	**6.19**	0.016/0.016	**0.00**	0.011/0.010	**9.09**	0.040/0.032	**20.00**	22.0/23.0	**-4.54**

Description: numerator - element content in steel before filtration,
denominator - element content in steel after filtration,
η - rate of element content changes.

TABLE 3

Average surface-share of all non-metallic inclusions in the filtrated and non-filtrated steel of the experimental melts related to intervals of the inclusion size according to Feret diameters

Test No	Symbol of the melt	Superficial share of all non metallic inclusions: Superficial, %	η_{NMI}, %	Superficial share of the inclusions with the diameter $F_x = 0.5 – 2.5$ μm: Superficial, %	η_{NMI}, %	Superficial share of the inclusions with the diameter $F_x = 2.6 – 6.5$ μm: Superficial, %	η_{NMI}, %	Superficial share of the inclusions with the diameter $F_x = 6.6 – 15.5$ μm: Superficial, %	η_{NMI}, %	Superficial share of the inclusions with the diameter $F_x = 15.5 - 30.0$ μm: Superficial, %	η_{NMI}, %
1	2	3	4	5	6	7	8	9	10	11	12
2	M-1	0.107/0.08	**25.23**	0.02/0.01	**50.00**	0.039/0.035	**10.26**	0.039/0.027	**30.77**	0.009/0.011	**- 22.22**
	M-2	0.15/0.11	**26.67**	0.014/0.016	**- 14.29**	0.069/0.044	**36.23**	0.045/0.049	**- 8.89**	0.021/0.004	**80.95**
	M-3	0.149/0.10	**32.89**	0.015/0.016	**- 6.67**	0.051/0.046	**9.80**	0.048/0.031	**35.42**	0.035/0.005	**85.71**
3	M-1	0.120/0.117	**2.50**	0.017/0.018	**- 5.88**	0.057/0.048	**15.79**	0.044/0.040	**9.09**	0.002/0.011	**- 45.00**
	M-2	0.103/0.101	**1.94**	0.020/0.021	**- 5.00**	0.050/0.040	**20.00**	0.023/0.032	**- 39.13**	0.010/0.008	**20.00**
	M-3	0.095/0.109	**- 14.74**	0.008/0.014	**- 75.00**	0.047/0.054	**- 14.89**	0.022/0.032	**- 45.45**	0.018/0.009	**50.00**
	M-4	0.174/0.120	**31.03**	0.033/0.016	**51.51**	0.098/0.061	**37.76**	0.034/0.040	**- 17.65**	0.009/0.003	**66.67**
	M-5	0.146/0.135	**7.53**	0.018/0.015	**16.67**	0.047/0.054	**- 14.89**	0.054/0.057	**- 5.56**	0.027/0.009	**66.67**
	M-6	0.136/0.099	**27.21**	0.009/0.013	**- 44.44**	0.046/0.037	**19.57**	0.051/0.045	**11.76**	0.03/0.004	**86.67**

TABLE 4

Average number of non-metallic inclusions in the filtrated and non-filtrated steel of the experimental melts related to intervals of inclusion size according to Feret diamters

Test No	Symbol of the melt	The number of all non metallic inclusions		The number of non metallic inclusions with the diameter $F_x = 0.5 - 2.5\ \mu m$		The number of non metallic inclusions with the diameter $F_x = 2.6 - 6.5\ \mu m$		The number of non metallic inclusions with the diameter $F_x = 6.6 - 15.5\ \mu m$		The number of non metallic inclusions with the diameter $F_x = 15.5 - 30\ \mu m$	
		Quantity. items.	η_{NMI}. %	Quantity. items	η_{NMI}. %	Quantity. items	η_{NMI}. %	Quantity. items	η_{NMI}. %	Quantity. items	η_{NMI}. %
1	2	3	4	5	6	7	8	9	10	11	12
2	M-1	238/172	**27.73**	146/89	**39.04**	70/68	**2.86**	20/13	**35.00**	2/2	**0.00**
	M-2	302/275	**8.94**	154/144	**6.49**	120/97	**19.17**	25/33	**- 32.00**	3/1	**66.67**
	M-3	270/295	**- 9.26**	115/158	**- 37.39**	117/118	**- 0.85**	33/18	**45.45**	5/1	**80.00**
3	M-1	313/304	**2.88**	175/187	**- 6.86**	110/89	**19.09**	27/22	**18.52**	1/6	**- 500.00**
	M-2	373/354	**5.09**	227/238	**-4.85**	125/94	**24.80**	19/17	**10.53**	2/5	**- 150.00**
	M-3	196/301	**- 53.57**	93/176	**- 89.25**	90/107	**- 18.89**	12/15	**- 25.00**	1/3	**- 200.00**
	M-4	612/306	**50.00**	377/178	**52.79**	209/101	**51.67**	23/25	**- 8.70**	3/2	**33.33**
	M-5	249/282	**- 13.25**	127/164	**- 29.13**	86/89	**- 3.49**	26/27	**- 3.85**	10/2	**80.00**
	M-6	214/234	**- 9.46**	107/137	**- 28.04**	82/74	**9.76**	22/20	**9.09**	3/3	**0.00**

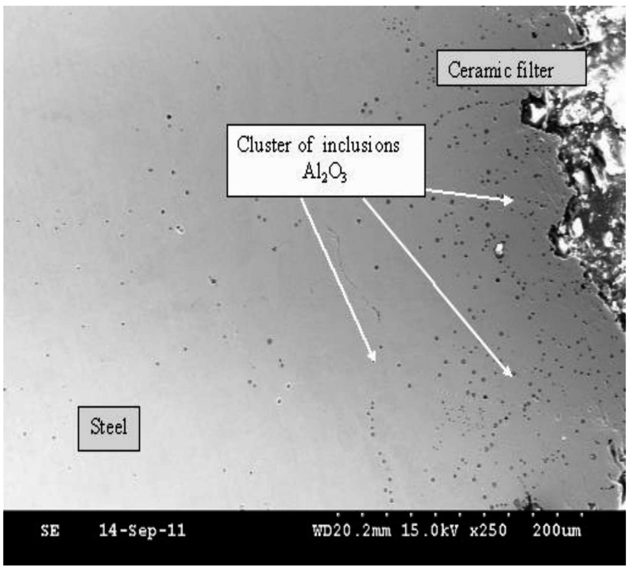


Fig. 9. Scaning pictures of interface partition filters ceramic – filtration steel of head – 34GJ steel

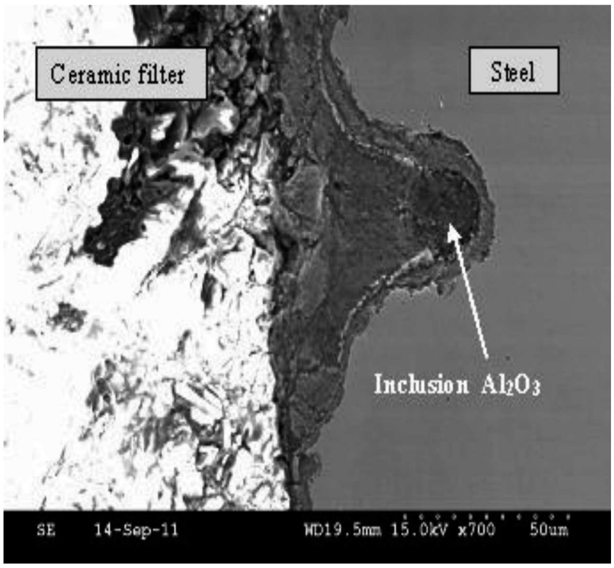


Fig. 10. Scaning pictures of interface partition filters ceramic – filtration steel of head – SE03 steel

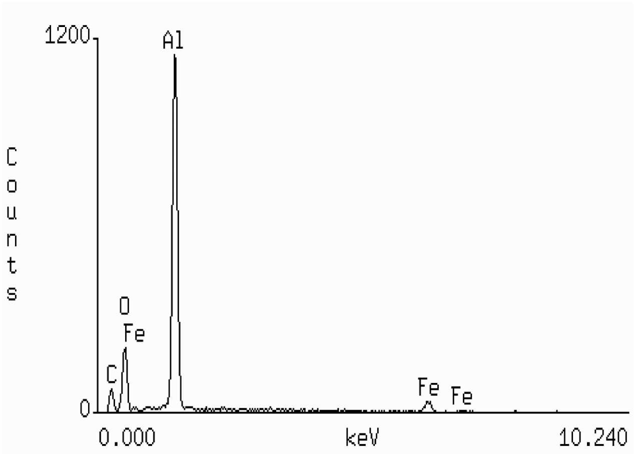


Fig. 11. X-ray photograph of non metallic inclusions chemical composition identified on the surface of a ceramic filter and in steel volume from melt – 34GJ steel

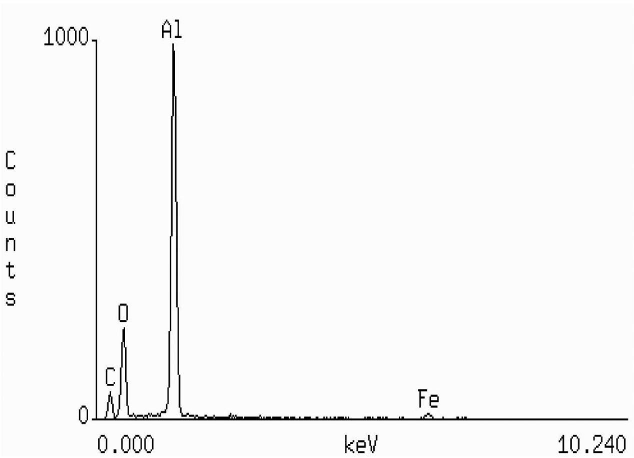


Fig. 12. X-ray photograph of non metallic inclusions chemical composition identified on the surface of a ceramic filter and in steel volume from melt – SE03 steel

5. Summary and conclusions

Based on the research carried out hitherto and the published results, a judgement should be made that liquid steel filtration with the ceramic filters can become in the nearest future the effective and cheap method of additional steel refining, in order to separate the non-metallic inclusions, as well as the permanent processing procedure in the continuous casting technology (for some types of steel). The model research has proved good liquid steel flow dynamics and steel mixing in the tundish provided with multi-hole filters in case of filter installation in the place of conventional overflow partitions. Placing the multi-hole filters in the position of conventional overflow partitions is the most beneficial filter location within the way of steel making process. The filtration trials carried out have not proved the earlier apprehension of emergency risk, have not thrown into confusion the continuous casting process and even have improved the liquid steel mixing dynamics in the tundish, as it has become evident after the model research. The filter washout effect discovered in its lower part (the third trial) should not be considered a surprise due to the fact that the quantity of liquid steel processed in each melt is about 330 Mg (during the second trial 990 Mg and during the third trial 1980 Mg liquid steel has been filtrated). The η_{WN} effectiveness of non-metallic inclusions removal, as measured by the average extent of variation in the inclusion surface share in filtrated and non-filtrated steel, has amounted 28,24% for the second and 9,24% for third trial with the filter slenderness ratio λ = 3,10. There is a one more positive effect of use of the multi-hole ceramic filters, which is the increased time of the ladle nozzle service life. If part of the non-metallic inclusions is stopped at the level of the tundish then the nozzle service life is decidedly increased (the process of decrease in the nozzle cross section runs more slowly).

Such big differences in the filtration effectiveness can be explained by the quantities of the filtrated steel. The filter ceramic material has been washed out towards the finish of the second trial. Yet, the results presented in this paper, of an experiment prepared and carried out in the industrial environment, are the only positive results obtained, which are connected with so much quantities of liquid steel processed with use of the multi-hole ceramic filters.

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