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Production of the highest quality cast steel using the AOD converter process

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Introduction

Modern castings should be characterized by a favorable combination of high strength and crack resistance in a wide range of temperatures and under various working conditions.

The requirements for the use of steel castings in extreme conditions concern low- to high-alloyed grades produced by secondary treatment of cast steel in order to obtain very precise regulation of the chemical composition and to ensure very high purity of the cast steel. There is a growing tendency in the world to replace the forged and welded elements in the construction of machines and devices with one-piece castings or elements composed of several castings. Economic development and the need to expand the–operations mean that materials, allowing for the use of castings in extreme operating conditions, including at minus 60°C (Arctic areas) or at depths greater than 3000 m (underwater areas), are increasingly in demand on the market. These market trends have become the basis for Odlewnia PIOMA to start work on developing cast steel for use in extreme conditions. Meeting the quality requirements of structural cast steel for applications in–low temperatures is associated with ensuring high quality, including mainly cast steel purity in modern processes of secondary refining of liquid metal.

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Introduction

PIOMA Odlewnia in Piotrkow Trybunalski is part of Polska Grupa Odlewnicza S.A. and is equipped with two arc furnaces with a capacity of 3 and 6 tons and two induction furnaces with a capacity of 3 tons each. Low-alloy cast steel is melted in arc furnaces and refined in the furnace and ladle during tapping. High-alloy steel castings for the energy (martensitic) and chemical (duplex) industries are melted in induction furnaces, using pure alloying components that make the casting production more expensive. The current quality of low-alloy structural cast steel produced in arc furnaces ensures that the required impact level of 40 J/cm2 at minus 40°C is met only for thin-walled castings up to 25 mm thickness.

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The main factors characterising high purity of cast steel include phosphorus, sulphur and total oxygen content. For low-alloy structural steel for work at temperatures down to minus 60°C their contents should be as follows: P – max. 0.005%; S – max. 0.002% and O_{tot} – max. 10 ppm (or 0.001%). The required K4 purity index (contamination with oxide and sulphide inclusions) according to DIN 50602 should be less than 10. For high-alloy steel with chromium and with very low carbon content, its content in finished cast steel may not be greater than 0.03%. The device for the secondary steel refining process should also provide very low (max. 0.004%) and high (0.20%) nitrogen content in the cast steel.

Obtaining such high purity is ensured by devices for secondary treatment of liquid cast steel such as: ladle furnace, VOD devices and AOD converter. In foundries using electric arc furnaces (EAF), AOD converters are often used due to the possibility of temperature control in a wide range.

Pioma Foundry Equipment – AOD Converter

The AOD device, the first in Poland, with a converter with a capacity of 8 tons, was supplied and built by the Swedish company UHT (UVAN HAGFORS TEKNOLOGI AB). Figure 1 shows the diagram of the AOD converter. In April 2019, the hot start was initiated under the supervision of this company, and then the initial operation of the converter was started. The AOD converter is supplied by 3 or 6 ton arc furnaces. The AOD converter is fully automated and controlled using the UTCAS level 2 process control system. Figures 2 to 4 show a view of the AOD converter at various stages of the process. The refractory lining of the converter in the working layer is made of magnesite materials with low carbon content.

Fig. 1. Diagram of the AOD converter operating in a Foundry Pioma

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Fig. 2. Tilt of the AOD converter for temperature measurement and sampling for chemical analysis

Fig. 3. Tilting the AOD converter for tapping the cast steel into the ladle

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AOD process at the Pioma foundry

The process in the AOD converter takes place in three stages. The first stage is chemical heating of the liquid metal supplied from the arc furnace. Chemical heating is based on oxidation of silicon in a metal bath with oxygen blown in argon shield gas through side nozzles.

The second stage – decarburization of the metal bath - is conducted with a variable ratio of blown nitrogen or oxygen and argon mixture and variable gas flow rate. After reaching the required carbon content in the metal bath, the third stage is carried out – deoxidation of the metal bath.

Then reduction of slag and correction of the chemical composition of liquid cast steel, when blowing only inert gas: argon or nitrogen takes place. It is worth mentioning that during the last 2 minutes of the process, gentle, rinsing mixing is used with a minimum flow of argon. After obtaining the assumed chemical composition of the metal sample and the temperature, the liquid cast steel is tapped into the foundry ladle. Figures 4 and 5 shows diagrams of the average total melting times and particular times for each of the AOD proces stages for low-alloy, high-alloy martensitic and low-carbon, high-chromium duplex cast steels.

AOD process at the Pioma foundry

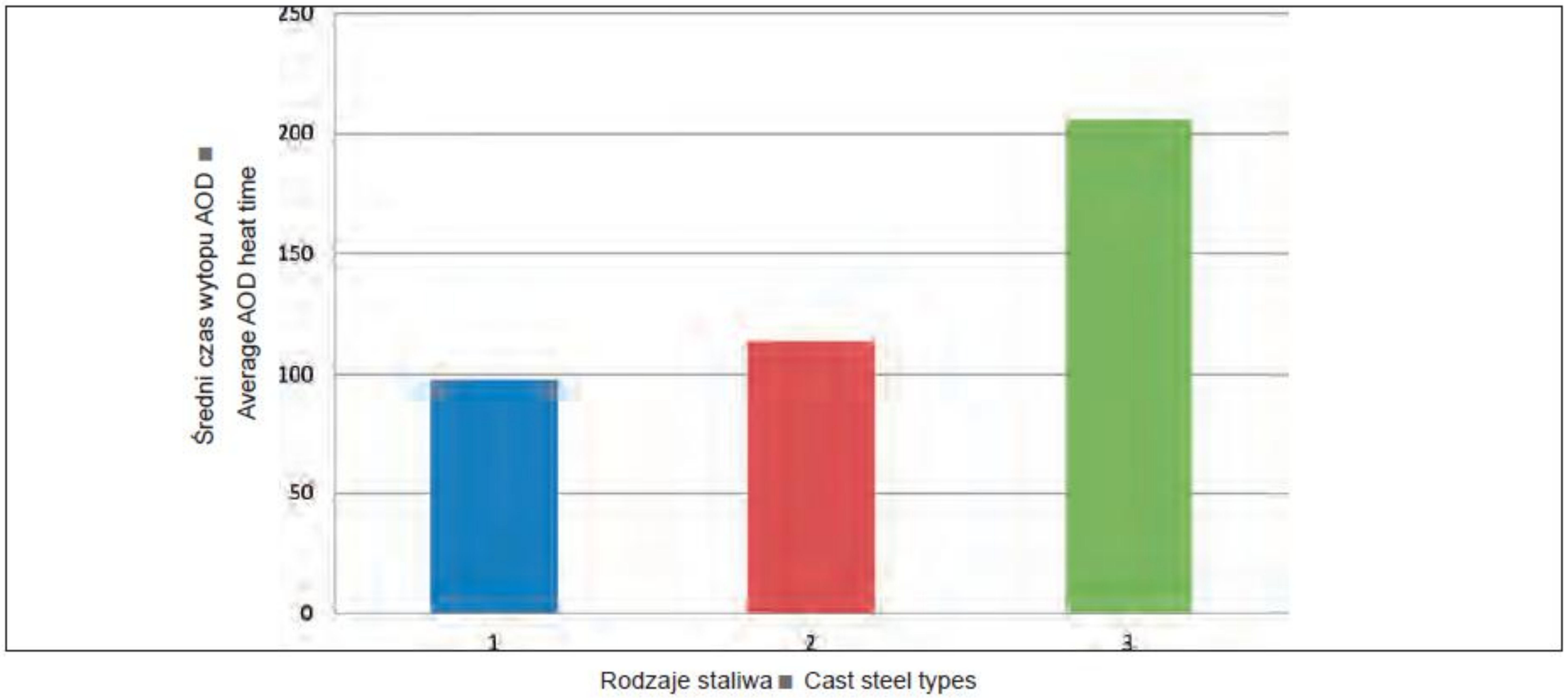

Fig. 4. Average heat time in AOD for 1 – low-alloy, 2 – martensitic and 3 – duplex steel

AOD process at the Pioma foundry

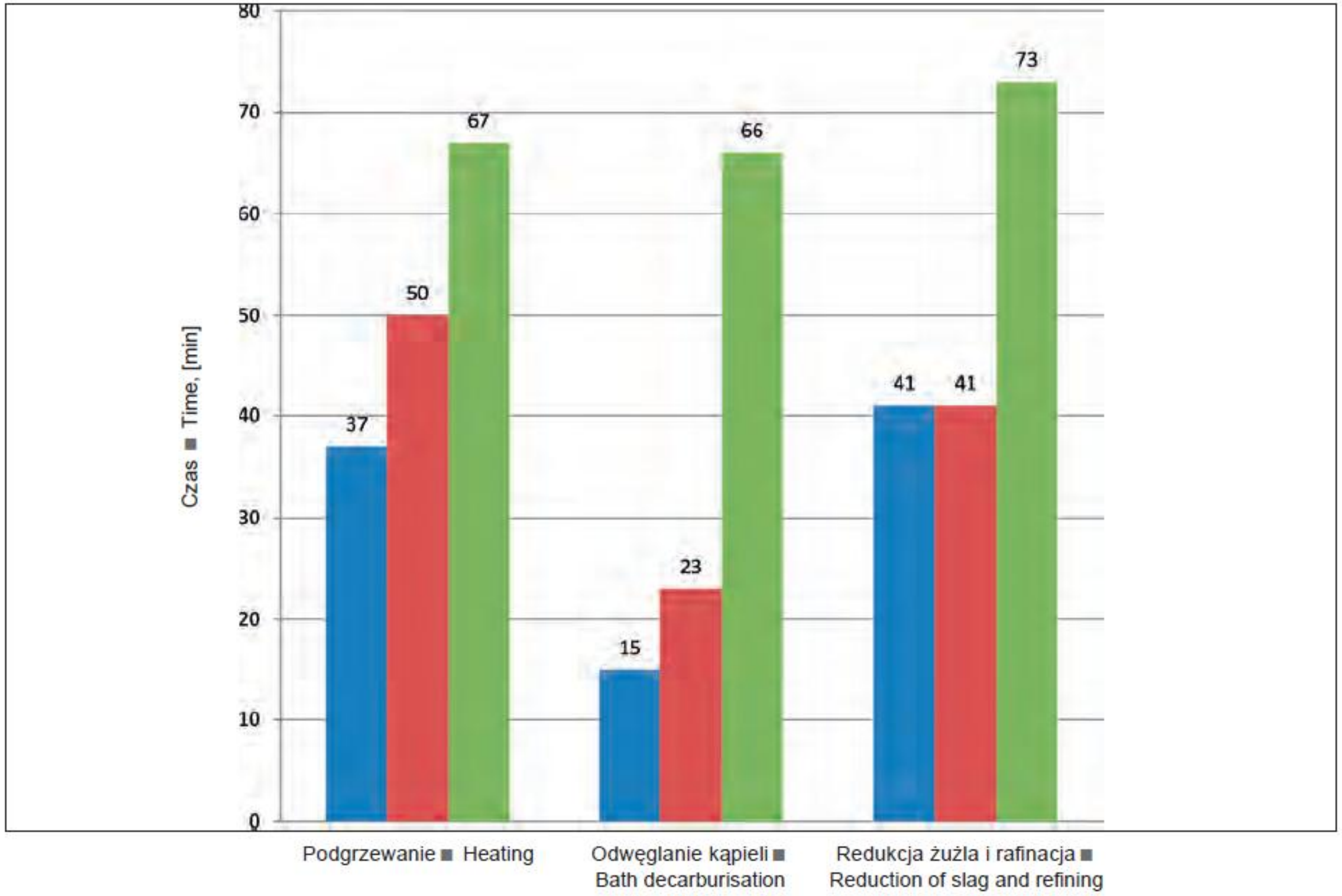

Fig. 5. The average time of the AOD proces stages for low-alloy (blue), martensitic (red) and duplex steel (green)

The scope of research

The research work included: production of the experimental steel castings for extreme working conditions from melts made in the AOD converter, including low-alloy structural cast steels for critical working conditions, martensitic cast steel and duplex cast steel. Table 1 shows the chemical compositions of cast steels for individual grade groups.

The tests were carried out on samples cut out from the witness tests– P1 (clovers) at a distance of approximately

20 mm from the upper surface ("head"). The examination of chemical composition of non-metallic inclusions was carried out using an Inspect F scanning microscope with a BSE detector, and for quantitative analysis of non-metallic inclusions, using a Nikon Epiphot 200 light microscope and an Inspect F scanning microscope.

The types of non-metallic inclusions characteristic for each cast steel grade are presented in Figures 6–8.

Generally, very fine complex oxides on a spinel matrix were observed, difficult to remove from cast steel, with MnS, TiN and AlN precipitated on them during solidification.

The scope of research

Table 1. Required chemical composition of cast steel grades for experimental castings produced by the AOD converter

Lp. ■ No.	Rodzaj stali ■ Steel type	Zakres zawartości pierwiastków, [% mas.] ■ Element content range, [wt %]										
	Gatunek ■ Grade	C	Si	Mn	P	S	Cr	Ni	Mo	Al	N	V
1	Do pracy w krytycznych warunkach (-25°C) ■ For operation in critical conditions (-25°C) A6 BS3100	0,27 0,31	0,30 0,50	1,35 1,55	max 0,020	max 0,015	max 0,15	max 0,10	0,10 0,12	0,02 0,04		max 0,05
2	Do pracy w krytycznych warunkach(-60°C) ■ For operation in critical conditions (-60°C) Grade135-125 CMS-01	0,13 0,20	0,20 0,60	0,60 1,00	max 0,015	max 0,005	0,55 1,00	1,50 2,00	0,35 0,55	0,01 0,03		0,03 0,06
3	Stal martenzytyczna ■ Martensitic steel GX12CrMoVNbN9-1 Stg9T, wg 9ANM ■ per 9ANM 600212	0,10 0,14	0,20 0,50	0,30 0,60	max 0,02	max 0,01	8,0 9,5	max 0,40	0,85 1,05	max 0,02	0,03 0,07	0,18 0,25 Nb 0,06 0,10
4	Stal F-A Duplex ■ F-A Duplex steel X 2CrNiMoN22-5-3 1.4462	max 0,03	max 1,0	max 2,0	max 0,035	max 0,015	21,0 23,0	4,5 6,5	2,5 3,5		0,10 0,22	

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Research results

Based on the research, modified chemical compositions were developed for castings made of the following steel grades:

- steel castings for use in the oil and gas extraction industry, e.g. grade 135-125 according to WS 236/CMS-01,
- steel castings for use at operating temperatures down to minus 60 ^{o}C in rail transport, e.g. grade DCAB500/600 D and E,
- castings made of corrosion-resistant duplex steel for use in the chemical industry and construction, e.g. grade GX2CrNiMoN22-5-3.

Research results

Assessment of non-metallic inclusions.

Generally, very fine complex oxides on a spinel matrix were observed, difficult to remove from cast steel with MnS, TiN and AlN precipitated on them during solidification.

Figures 6, 7 and 8 show the types of inclusions observed in castings.

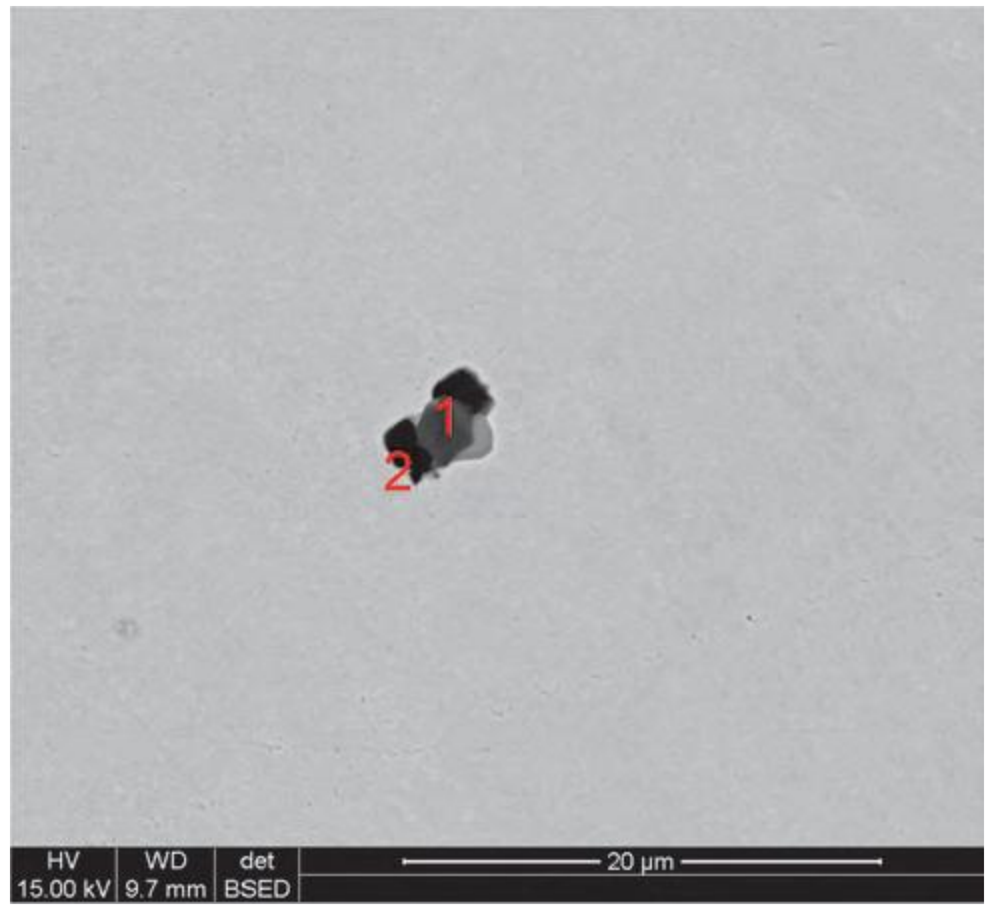

Fig. 6. Complex non-metallic inclusions in a sample of low-alloy cast steel, grade A6, AOD heat No. 50024 (chemical composition of the cast in weight %: C – 0.14; Mn – 1.43; Si – 0.49; P – 0.018; S – 0.003; Cr – 0.15; Ni – 0.12; Mo – 0.12; Al – 0.02; N – 0.0078);

Inclusion composition: 1 – TiO_2 ・ MgO ・ Al_2O_3 +MnS; 2 – (Ti,Al)N

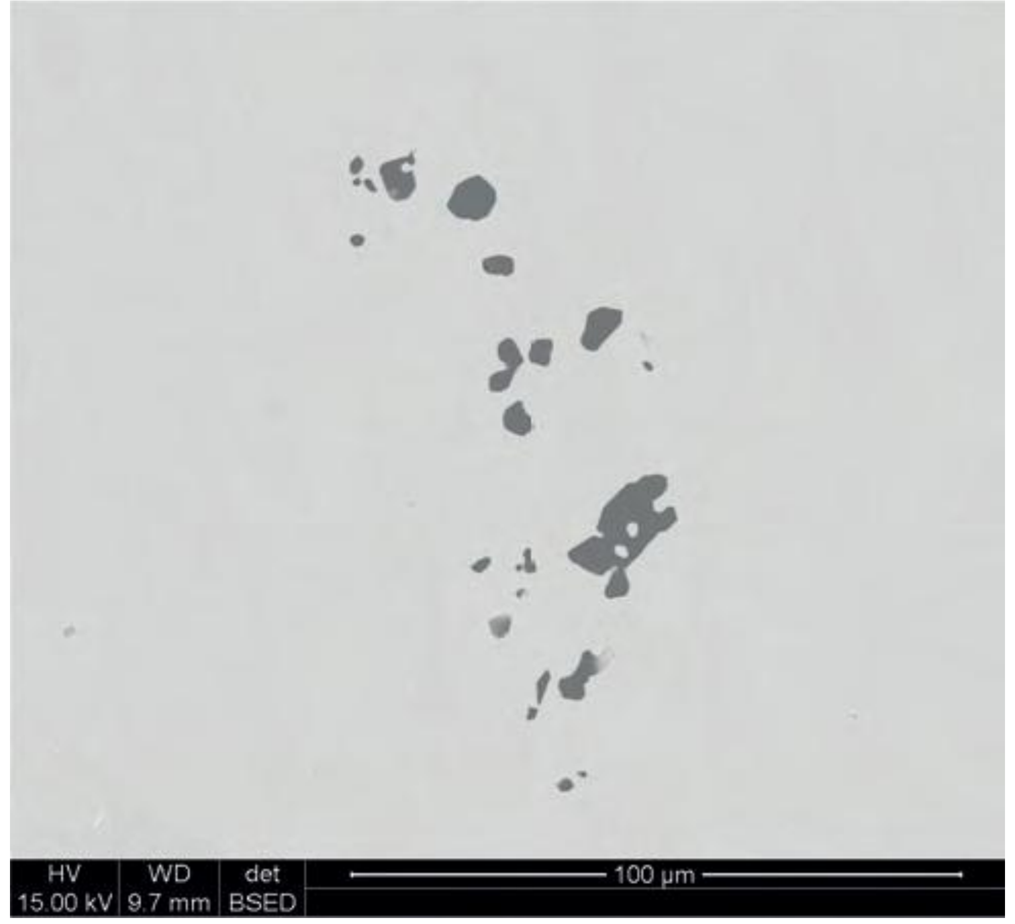

Fig. 7. Non-metallic inclusions in the sample of cast steel GX12CrMoVNbN9-1 9martensitic), heat No No 50005 (chemical composition in weight %: C-0,087; Mn-0,51; Si-0,42: P-0,019; S-0,012; Cr- 9,27; Ni-0,26 Mo-0,86; Al-0,017;V-0,22; Nb-0,086;N-0,0475, cluster Al_2O_3

Research results

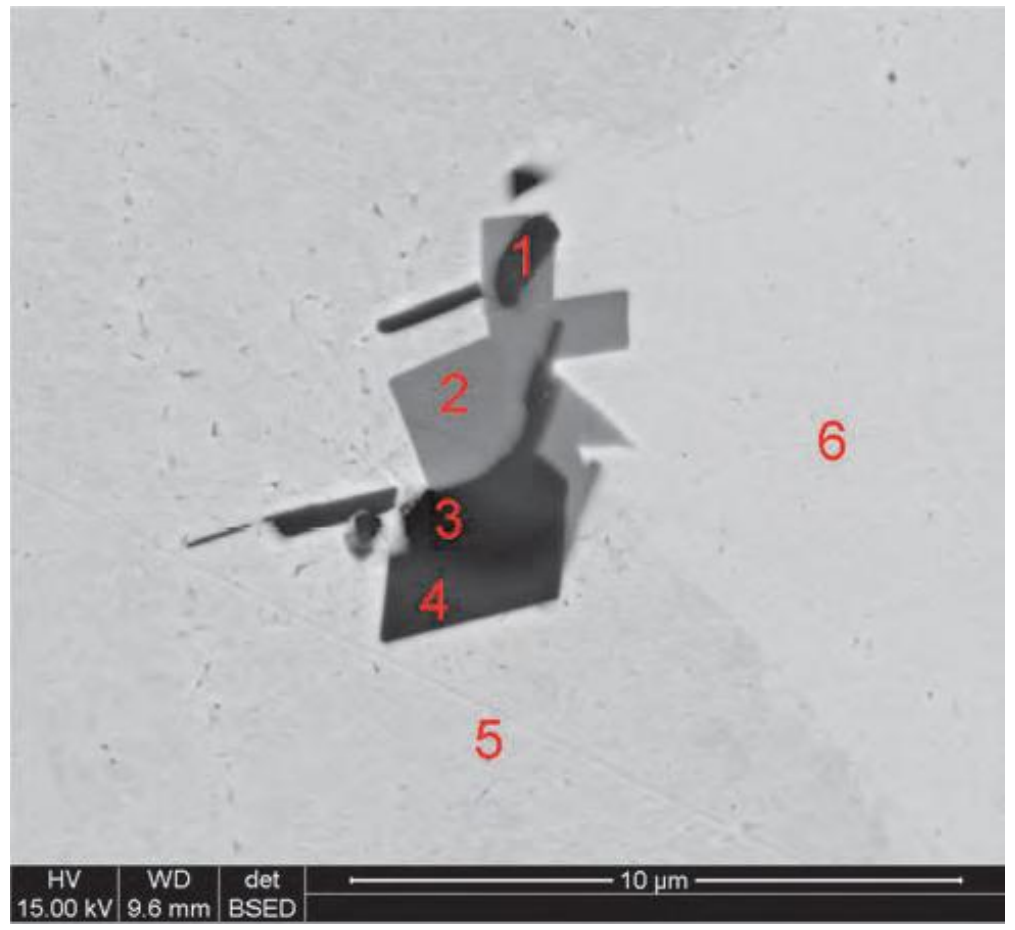

Fig. 8. Complex non-metallic inclusion in the cast steel GX2CrNiMoN22-5-3 (duplex), heat 50025, chemical composition of the cast in weight %: : C – 0,10; Mn – 0,52; Si – 0,94; P – 0,022; S – 0,0017; Cr – 20,95; Ni – 4,86; Mo – 2,52; Al – 0,087; V – 0,034; N – 0,20);
1 – – $TiO_2 \cdot CaO \cdot MgO \cdot Cr_2O_3 \cdot Al_2O_3$, 2 – TiN, 3 –
– $TiO_2 \cdot MgO \cdot Cr_2O_3 \cdot Al_2O_3$, 4 – MgO · Cr2O3 · Al_2O_3, 5 – ferrite, 6 – austenite

Research results

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Table 2. Purity indicators of cast steel produced in-the AOD converter from early operation and from traditional technology

Indicator, average value	Unite of meas.	AOD technology		Traditional technology	
		To be obtained	Currently obtained	Arc furnance	Induction furnance
K 4 (S + O)	-	< 10	14	35	-
$O_{całk}$	ppm	<10	30	55	59
P	%	<0,005	0,004	0,010	0,012
S	%	<0,002	0,0018	0,007	0,010
C	%	<0,03	0,0195[1)]/0,024[2)]	0,09	0,03

Notes: 1) after decarburisation in the AOD converter, 2) in a finished duplex cast

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Table 3. Data table of the K4 coefficient, total oxygen content, area fraction of inclusions and porosity, and average equivalent diameter of inclusions in experimental castings made according to traditional technology, in EAF (T), induction furnace (TI) and demonstration technology (AOD)

Lp. ■ No.	Numer wytopu, Technologia ■ Heat number, Technology	Gatunek staliwa/grupa ■ Cast steel grade/group	Wartość K4 ■ K4 value [–]	Zawartość $O_{całk}$ ■ $O_{całk}$ content [ppm]	Udział powierzchniowy wtrąceń i porowatości ■ Surface fraction of inclusions and porosity [%]	Średnia średnica równoważna wtrąceń ■ Average equivalent diameter of inclusions [µm]
1	50001,AOD	A6/niskostopowe ■ low-alloy	10	-	0,02	5,43
2	50003,AOD	135-125 CMS-01 niskostopowe ■ low-alloy	–	40	–	–
3	50005,AOD	GX12CrMoVNb9-1 martenzytyczne ■ martensitic	20	56	0,07	2,55
4	50009,AOD	GS20Mn5/niskostopowe ■ low-alloy	60	-	0,01	4,83
5	50011,AOD	A6/niskostopowe ■ low-alloy	10	–	0,16	2,91
6	50024,AOD	A6/niskostopowe ■ low-alloy	10	–	0,05	2,68
7	50025/1,AOD	GX2CrNiMoN22–5-3 duplex	40	51	0,28	2,15
8	50025/2,AOD	GX2CrNiMoN22-5-3 duplex	–	38	0,25	2,18
9	50029,AOD	G9Ni10 martenzytyczne ■ martensitic	–	40	–	–
10	50032/AOD	A6/niskostopowe ■ low-alloy	–	33		
11	50033/AOD	A6/niskostopowe ■ low-alloy	–	46		
12	26274T	L35HM/niskostopowe ■ low-alloy	–	74	0,13	2,95
13	26313T	G32NiCrMo8–5-4/średniostopowe ■ medium-alloy	–	–	0,11	2,77
14	26343T	GD42CrMo4/niskostopowe ■ low-alloy	–	67	0,11	3,16
15	60391T	120-110/niskostopowe ■ low-alloy	–	46	0,10	3,37
16	69841T	DCAB500D/niskostopowe ■ low-alloy	–	61	0,11	3,32
17	71515TI	GX5CrNi19-10/wysokostopowe ■ high-alloy	–	61	0,07	2,71
18	71559TI	DCAB600D/niskostopowe ■ low-alloy	–	54	0,14	3,86
19	71560TI	GX12CrMoNbN9-1/wysokostopowe ■ high-alloy	–	62	0,08	2,91

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Summary

1. The start of the AOD converter, the first in Poland, at the Pioma Foundry allowed the production of castings for extreme operating conditions. The technology of melting low-alloy cast steel in the arc furnace - AOD converter technology line allows for obtaining cast steel:

- with a low content of non-metallic inclusions below 0.05% by area share,
- with a low sulfur content below 0.002%, and thus castings with high impact strength at temperatures down to minus 60 ^{o}C.

2. This enables the production of castings with high impact strength of min. 40 J/cm^2 at a temperature of minus 60 ^{o}C.

3. The technology of melting high-alloy cast steel in the arc furnace - AOD converter technology line allows for obtaining high-chromium duplex cast steel, with a carbon content in the liquid metal bath less than 0.02% by weight.

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Thank you for your attention!

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