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RESEARCH OF LIQUID ALUMINIUM ALLOYS AT PARTICULAR STAGES OF MANUFACTURING PROCESS

BADANIE CIEKŁYCH STOPÓW ALUMINIUM NA POSZCZEGÓLNYCH ETAPACH PROCESU TECHNOLOGICZNEGO

Requirements, placed by design engineers in relation to special castings, applied to gas filled high voltage switchgears PN-EN 50052:2002, are still higher. These demands concern to quality of machined sealing surface, assurance of castings leaktightness for a long time of operating and suitable strength during special bursting test. Manufacturer of such castings is obliged to use, among other things, high quality new alloy and guarantee proper metallurgical treatment and liquid alloy control during metal melting and preparation, before filling the moulds.

Generally new alloy testing is made by its producer. Receiver checks testing results, according to effective procedures, during incoming inspection.

Following tests are carried out during liquid alloy preparation (melting, degassing and inoculation): chemical composition test, thermal analysis and density index.

To confirm that the process of liquid alloy control is correct comparative examinations were made, using new installations of companies such as Foseco, ALSPEK* H, and metallographic examinations of special samples with computer picture analysis.

All examinations were made for one heat of AlSi7Mg0.3 alloy (AC – 42100 according to PN-EN 1706:2011), at different stages of liquid metal preparation, such as: in melting furnace, after reladle, after refining and just before filling sand moulds. Additionally alloy purity index, hydrogen content in liquid alloy, porosity degree were determined and also analysis of inclusions was made.

Examinations with applying modern devices confirmed, that the process of preparation and testing of liquid alloy, intended to produce castings of special requirements, is correct. All applied refining treatments improved liquid alloy quality, eliminated number of inclusions, porosity and reduced hydrogen content. It is a base for stating that high quality alloy, correctly prepared and controlled before filling sand mould was used.

New Foseco devices can be used in foundries to verify their processes of alloy preparation and alloy purity evaluation on different stages, especially producing castings of high technical requirements.

The thixotropy phenomenon is strongly connected with the change of viscosity in time, while the of Navier-Stockes equation. The micro- and macroscale models are coupled using CAFE approach.

Keywords: Al-Si alloy, degassing, inoculationto grain refining, metal testing

Konstruktorzy stawiają coraz wyższe wymagania dla specjalnych odlewów stosowanych w wysokonapięciowych rozdzielniach napełnianych gazem (PN–EN 50052:2002). Wymagania dotyczą jakości powierzchni uszczelniających po obróbce mechanicznej, zapewnienia szczelności odlewów w długim okresie ekspolatacji oraz odpowiedniej wytrzymałości w specjalnej próbie na rozrywanie. Dla producenta takich odlewów niezbędne jest stosowanie między innymi wysokiej jakości stopów wyjściowych oraz zapewnienie w procesie produkcyjnym topienia i przygotowania właściwej obróbki metalurgicznej oraz kontroli ciekłego stopu, jeszcze przed zalaniem form.

Powszechnie stosowane są badania jakości materiału wsadowego przez producenta. Odbiorca sprawdza wyniki badań w czasie kontroli wejściowej w ramach obowiązujących procedur. W trakcie przygotowania ciekłego stopu (topienie, rafinacja, modyfikacja) przeprowadzane są badania składu chemicznego, wykonywana jest analiza termiczna stopuoraz określony indeks gęstości.

Dla sprawdzenia poprawności stosowanego procesu kontroli ciekłego stopu dokonano pełniejszych badań porównawczych z zastosowaniem nowych urządzeń firmy Foseco, Alspek*H, Alspek MQ oraz badań metalograficznych na specjalnych próbkach z zastosowaniem komputerowej analizy obrazu.

Badania przeprowadzono dla jednego wytopu stopu AlSi7Mg0,3 (AC – 42100 wg PN-EN 1706:2011) w różnych etapach przygotowania, tj. w piecu topialnym, po przelaniu do kadzi przewoźnej, po procesie uszlachetniania oraz bezpośrednio przed zalaniem do form piaskowych. Dodatkowo określono indeks czystości stopu, zawartość wodoru w ciekłym stopie a także wykonano analizę wtrąceń i określono stopień porowatości.

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Wyniki badań przeprowadzone z zastosowaniem nowych urządzeń potwierdziły prawidłowość stosowanej technologii przygotowania i badania ciekłego stopu przeznaczonego na odpowiedzialne odlewy o specjalnych wymaganiach. Stosowane zabiegi uszlachetniania poprawiają w kolejnych zabiegach jakość ciekłego stopu, eliminują ilość wtrąceń, porowatość i zmniejszają zawartość wodoru. Daje to podstawę do oceny, że stosuje się dobrej jakości stop wyjściowy, jest on przygotowany i skontrolowany przed zalaniem formy piaskowej.

Nowe urządzenia firmy Foseco mogą być przydatne w odlewniach do weryfikacji stosowanego procesu przygotowania stopu i oceny jego czystości na różnych etapach, zwłaszcza produkujących odlewy o wysokich wymaganiach technicznych.

1. Introduction

Design engineers are making ever higher demands for special aluminium alloy castings, deployed in high-voltage gas filled switchgears (PN-EN 50052:2002) [1]. Requirements apply to quality of machined sealing surface, ensure leaktightness of castings during long period of using and suitable strength in special bursting test. Manufacturer of such castings is obliged to use high quality alloys and to guarantee proper metallurgical treatment and control of liquid alloy before pouring it to the mould. That must be secured by its production process of liquid alloy melting and preparation.

ZM „WSK – RZESZÓW" production program includes, among other products, castings for power industry, made of AlSi7Mg0.3 alloy with T6 heat treatment, performed in sand casting technology.

Within the framework of liquid alloy inspections following tests are carried out: chemical composition test, thermal analysis and density index. To confirm that the process of liquid alloy control is correct comparative examinations were made, using new installations of companies such as Foseco, ALSPEK* H, ALSPEK MQ [2], together with microsection computer analysis on special samples [3].

Examinations were made for AlSi7Mg0.3 alloy at different stages of the preparation process for casting. Following parameters were checked: quality of new alloy, purity index and hydrogen content in liquid alloy, inclusions and porosity analysis.

Alloy preparation

For the production of castings it is used AlSi7Mg0.3 alloy (EN AB 42100 according PN-EN 1676:2011), in pigs, in accordance with standard and special technical conditions.

Alloy melting takes place in crucible gas furnace. The charge consists in 100% of purchased material. After melting a sample is taken to check chemical composition. Conformity of chemical composition with requirements is a basis to release the alloy for next operations. Alloy is heated before pouring it out from a furnace to the temperature, which ensures technological temperature of casting. Alloy surface is purified using fluxing agent. Next alloy is refined and modified at a special stand. After finishing purifying treatment samples for Thermal analysis and density index examinations are taken. Chemical composition is examined once again to check modification effect.

If the examination results are good alloy is released for pouring.

Program of research

All quality examinations were made for one melting furnace heat of AlSi7Mg0.3 alloy (EN AC 42100 according PN-EN 1706:2011). Charge material was checked during inspection of delivery (chemical composition, macro- and microstructure, fracture). Then liquid metal was examined in melting furnace, in a ladle (before and after degassing, inoculation and grain refining), and before pouring to the moulds.

The following tests were carried out:

- temperature measurement,
- chemical composition examination,
- thermal analysis, which was the base to determine effectiveness of modification and grain refining,
- density index.

Examinations made using Foseco devices:

- hydrogen content in liquid alloy,
- metal purity index – MQI,
- computer analysis of alloy purity on samples poured into special die.

The program of liquid alloy research and the places, where samples were taken, are shown in Table 1.

Hydrogen content was checked using device ALSPEK* H, and metal purity index was determined on device ALSPEK MQ. Inclusions analysis was performed on samples poured into special die – Fig. 1. The samples were taken at each tested step of process. The sample has a shape of a bar with notches dividing the bar into four equal parts – Fig. 2. Notches are then used to make a fracture and to visually evaluate impurities.

Next stage of research was computer analysis of impurities. This method requires using of scanning microscope and a program for picture analysis. For the study it is necessary to prepare microsection (surface 100 mm^2) from sample No 4 (Fig. 2), which is then scanned. The program identifies and analyzes porosity, aluminum oxides and other oxides present in sample. They are counted and classified according to quantity.

Computer analysis was performed in Foseco laboratories.

TABLE 1

Places of taking samples for liquid alloy research

Places of taking samples	Type of examinations						
	Temperature	Chemical composition	Thermal Analysis	Density index	Hydrogen content	Metal purity index	Inclusions analysis
Melting furnace	x	x		x	x	x	x
Ladle / after pouring from furnace	x			x	x	x	x
Ladle / after refining, modification and grain refining	x	x	x	x	x	x	x
Ladle / before pouring to the moulds	x				x	x	x

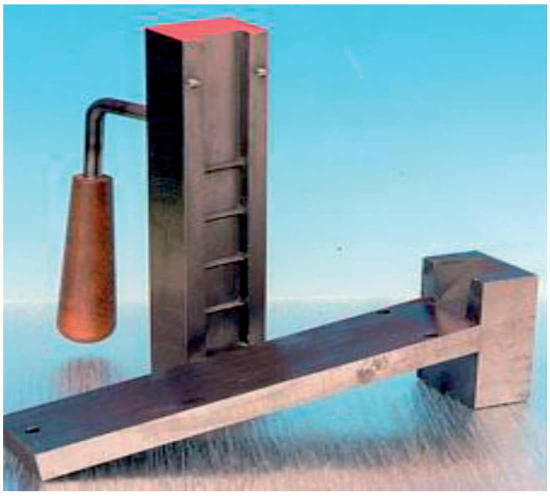

Fig. 1. The die for casting samples

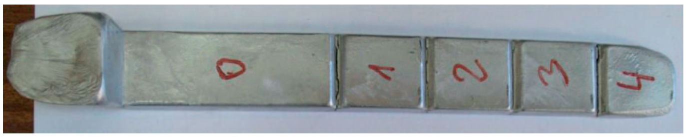

Fig. 2. The sample for fracture examination and purity analysis

Results of research

In Table 2 there are placed chemical composition results according to: certificate of manufacturer and examinations during inspection of delivery. Figures 3-5 show fracture and macro- and microstructure of tested pig.

TABLE 2

Chemical composition results of charge material, (wt.%)

	Si	**Fe**	**Cu**	**Mn**	**Mg**	**Ni**	**Zn**	**Ti**
min	***6,50***	***0,00***	***0,000***	***0,000***	***0,25***	***0,000***	***0,000***	***0,080***
max	***7,50***	***0,10***	***0,003***	***0,100***	***0,45***	***0,030***	***0,050***	***0,150***
Alloy Manufacturer	7,00	0,08	0,001	0,019	0,40	0,004	0,002	0,125
ZM WSK	7,10	0,08	0,002	0,018	0,39	0,004	0,002	0,120

Results of measurements of temperature, density index, hydrogen content, metal purity index and sodium content are placed in Table 3. Description of interpretation of metal purity index (MQI) is presented in Table 4. Fig. 6 shows printouts of examination of thermal analysis together with assessment of modification and grain refining effects. Fig. 7 presents appearance of fractures obtained on special sample, cast from melting furnace. The picture of microsection, prepared for computer analysis, is placed in Fig. 8. Table 5 includes cumulative results of evaluation of quantity and type of impurities. Graphic results are presented in Fig. 8-12.

Fig. 3. Fracture of pig

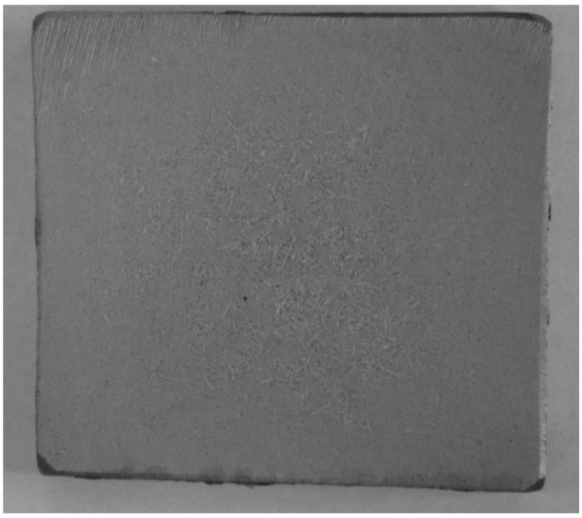

Fig. 4. Macrostructure of pig (etching 20% NaOH)

TABLE 3

Results of alloy research at different stages of preparation

Places of taking samples	Type of examinations					
	Time	Tempe-rature (°C)	Chemical composition - Na (%)	Density index (%)	Hydrogen content (ml/100g)	Metal purity index (MQI)
Melting furnace	15.30	759	0,0008	3,3	0,61	3
Ladle / after pouring from furnace	15.45	752	–	3,4	0,50	3,5
Ladle / after refining, modification and grain refining	15.55	730	0,0080	1,2	0,13	2,5
Ladle / before pouring to the moulds	16.05	715	–	–	0,15	1

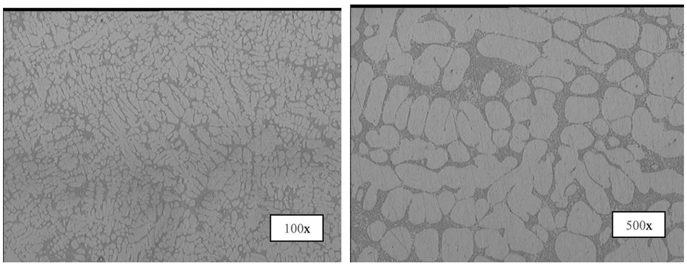

Fig. 5. Microstructure of pig (magnification 100x and 500x

Fig. 7. Examination of fracture on particular parts of sample, cast from melting furnace

TABLE 4

Designation of metal purity index MQI

MQI 1 i MQI 2	Very pure alloy, recommended for high quality, reliable castings
MQI 3	Pure alloy, recommended for standard castings
MQI 4 i MQI 5	Alloy with small quantity of oxide impurities, required refining
MQI 6 i MQI 7	Alloy containing big quantity of impurities, required longer refining
MQI 8	Alloy very impure
MQI 9	Very impure alloy, with impurities which block flow in filter

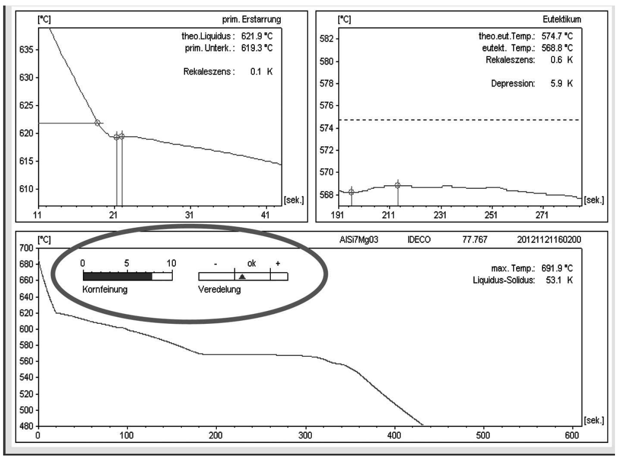

Fig. 6. Thermal analysis printout: factor grain refining factor is 7.8, (required min. 5.0), modification factor is 4.8 (required min. 4.0)

TABLE 5

Results of quality examination of liquid alloy

Specification	Place of examination			
	Melting furnace	Ladle/after pouring from furnace	Ladle/after refining, modification and grain refining	Ladle/before pouring to the moulds
Metal purity index (MQI)	3.0	3.5	2.5	1.0
Impurities	863	1009	267	471
Impurities				
All inclusions	420	493	130	229
Pores	356	423	112	188
Aluminium oxides	38	44	8	22
Other oxides	26	26	10	19
Clusters of oxides	23	23	7	13
Size of impurities				
0.50 – 2.50 μm	190	151	36	59
2.50 – 5.00 μm	135	177	51	97
5.00 – 15.0 μm	92	146	41	69
15.0 – 30.0 μm	3	18	2	4
30.0 – 75.0 μm	0	1	0	0

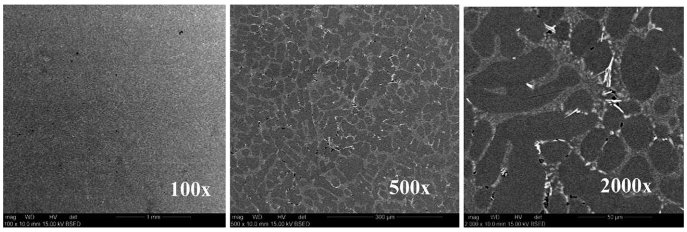

Fig. 8. Microstructure of alloy – ladle, before pouring to the moulds

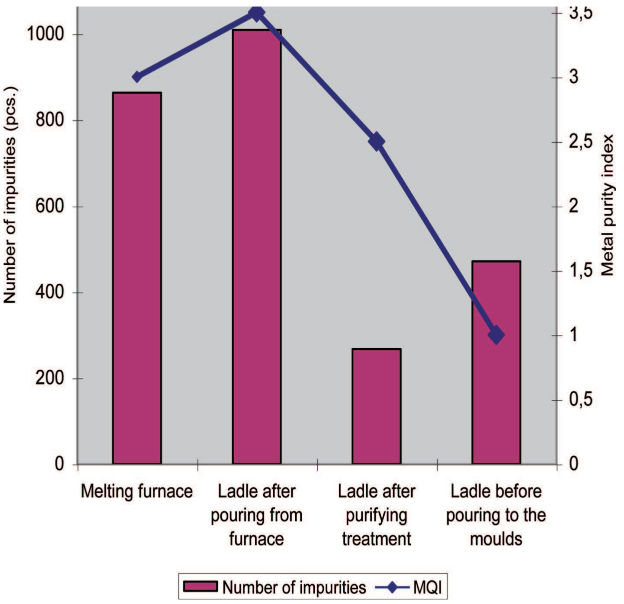

Fig. 9. Comparison of metal purity index MQI and number of impurities

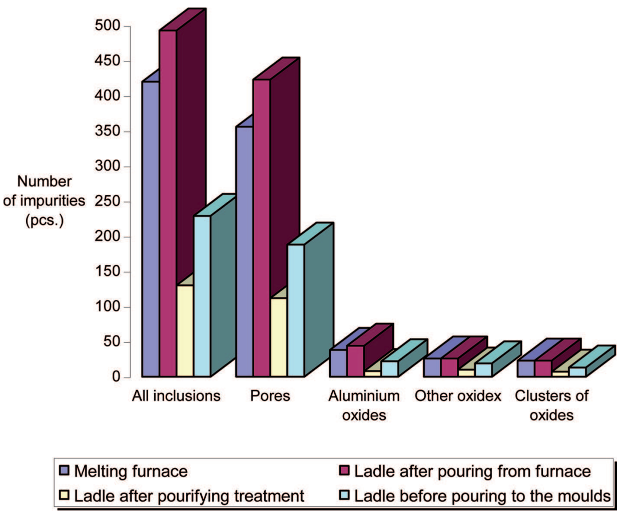

Fig. 10. Types and number of identified impurities

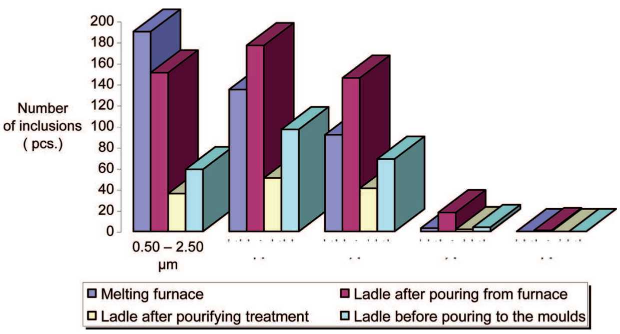

Fig. 11. Size and number of inclusions

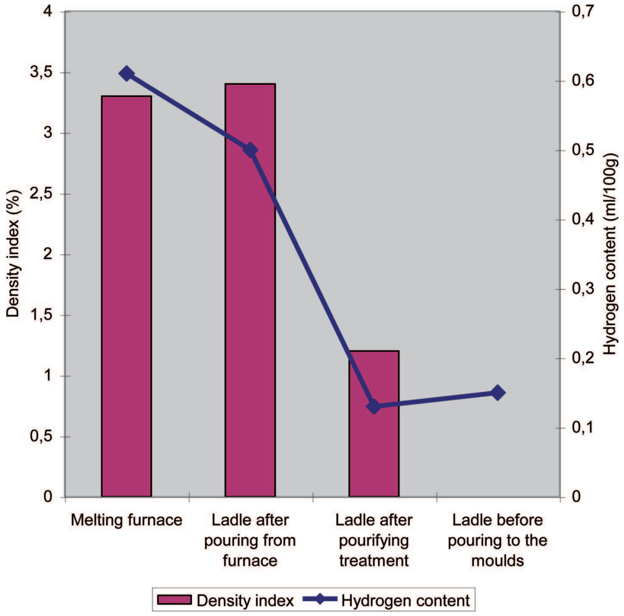

Fig. 12. Comparison of density index and hydrogen content in liquid alloy

Analysis of the results

1. Basing on examinations carried out during inspection of delivery it was stated, that the quality of charge material is conforming to requirements. Results obtained for samples taken from melting furnace acknowledge purity of alloy. The samples have good metal purity index MQI – 3. There are no inclusions, visible to the naked eye, on fractures of the sample taken from melting furnace.
2. During pouring metal from melting furnace to ladle the quantity of all types of analyzed inclusions, oxides and pores, particularly of size 2.5÷15.0 μm, increases. Metal purity index MQI is getting worse, too, to the value 3.5.
3. Refining has an effect on purification of alloy. Metal purity index MQI improves to the value 2.5, hydrogen content decreases to 0,13 ml/100g. Density index is 1.2%, what conforms to requirements (max 2.0%). Result of alloy thermal analysis also conforms to requirements. Modification index, which is 5.8, is shown in Fig. 6 in the field OK (required factor is min 4.0) . That result is confirmed also by content of sodium, introduced into alloy during modification, which is 80 ppm (required 50-90 ppm). Grain refining index, after introduce TiB, is correct (factor is 7.8 and required one is min 5.0).
4. Examinations performed in a ladle 10 minutes after the end of treatment demonstrated increase of total quantity of inclusions and pores by 43% in relation to the quantity after refining. The growth was observed for all analyzed ranges of inclusions and pores. Hydrogen content increased, too. There is no information about change of density index because the test was not carried out (technical problems).
   While waiting after refining, metal purity index has improved (MQI – 1).
5. ALSPEK MQ device catches inclusions with size over 50 μm.

During those 10 minutes of keeping metal in ladle before pouring to the moulds number of inclusions increased, but the size of them was below 50 μm. That was why the value of MQI index did not increase. That fact, however, drew attention to the need of small modification of the process. Now after refining, modification and grain refining, a fluxing agent is poured on the surface of liquid metal and the ladle is covered with a special lid. Before pouring alloy to the moulds the lid is taken off and melting loss, formed on metal surface, is removed.

6. The alloy, which is poured to the moulds, has purity index MQI 1, and, according to examinations made on ALSPEK MQ, it is a high purity alloy, which is recommended to perform high quality castings (Table 4).

Conclusions

- The technology of preparation and inspection of metal provides getting high quality liquid alloy for the production of sand castings, used in gas filled high-voltage switchgears.
- Purity level of metal in melting furnace confirmed good quality of charge material. Small quantity of inclusions was detected after pouring the metal to the ladle.
- Refining the alloy with argon is effective and decrease quantity of impurities by 73.5%.
- Small increase of impurities of size below 50 μm was observed just before pouring the metal to the moulds.

REFERENCES

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