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HYDROGEN CONTENT CONTROL DURING STEEL MELTING PROCESS AT FORGED PRODUCT PLANT OF CELSA "HUTA OSTROWIEC"

KONTROLA ZAWARTOŚCI WODORU PODCZAS PRODUKCJI STALI W ZAKŁADZIE WYROBÓW KUTYCH CELSA „HUTA OSTROWIEC"

In this paper the description and analyze of issues connected with activities which aim is to lower hydrogen content in steel manufactured in Forged Product Plant CELSA "Huta Ostrowiec". Currently the problem of strain-hydrogen cracks of forgings does not exist, however increasing requirements of our customers concerning steel cleanness may result in reactivating its. Due to that improvement of metallurgic steel cleanness must be parallel to decrease of hydrogen content. The investigations of hydrogen content in liquid steel after tapping, before vacuum degassing, after vacuum degassing and after casting to moulds were carried out. According to tests it comes out that besides vacuum degassing the most important factor influencing hydrogen content in ingots is effectiveness of liquid steel protection during casting to moulds to avoid re-hydrogenation.

W artykule przestawiono opis i analizę działań zmierzających do zmniejszenia zawartości wodoru w stalach produkowanych w Zakładzie Wyrobów Kutych Celsa „Huta Ostrowiec". Aktualnie problem pęknięć wodorowych w produkowanych odkuwkach nie istnieje, jednak wzrastające wymagania klientów w zakresie czystości metalurgicznej stali mogą spowodować powstanie takiego problemu. Z tego powodu zwiększanie czystości metalurgicznej stali wymusza działania w kierunku zmniejszenia zawartości wodoru w stali. Przedstawiono wyniki badań zawartości wodoru w ciekłej stali po spuście z pieca, przed próżniowym odgazowaniem, po odgazowaniu oraz po odlaniu do wlewnicy. Wyniki badań wskazały, że poza procesem odgazowania najważniejszym czynnikiem zwiększającym zawartość wodoru w stali jest skuteczność ochrony ciekłej stali podczas odlewania przed działaniem atmosfery powietrza.

1. Introduction

A problem of hydrogen content in steel has been subject of many researches and publications for a long time. From one side it proves great importance of that problem in practice, from the other hand it confirms complexity of mechanisms of hydrogen influence on metals' characteristics. Due to high chemical reactivity, significant mobility, complexity of phenomenons connected with trapping of hydrogen in crystal structure defected areas, and also occurrence in steel in small quantities (p.p.m. level) the mechanism describing hydrogen influence on characteristics is extremely complicated. [1,2]. However, numerous researches allowed to understand a number of cases connected with hydrogen influence on technical ferrous alloys. It is generally known that hydrogen has negative effect on mechanical properties (hydrogen embrittlement). It also impacts on appearance of internal cracks in forgings called snowflakes (Fig. 1). Such defects are detected

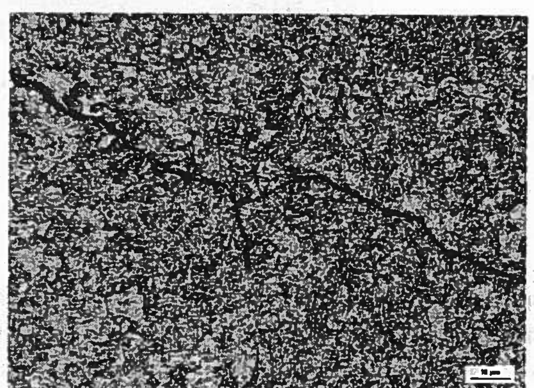

Fig. 1. Image of strain-hydrogen crack in steel grade S34MnV

using ultrasonic method and occur mostly in internal zones of products with big cross-sections. Mechanism of

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snowflakes occurrence is very complicated and not fully known however all main factors which causes this effect are identified. Most important ones are hydrogen content and local strains. Distinctive feature of hydrogen-caused cracks is that they appear after incubation period with temperature under 200°C, often in places with strong positive segregation of alloy contents [3,4].

Strain-hydrogen cracks were a serious problem during production of heavy forgings before liquid steel vacuum degassing equipment was introduced. Those defects were the most common reason for scrapped parts. Vacuum degassing treatment allowed to lower hydrogen content in steel under 2 ppm, due to that hydrogen problem was generally controlled. Since that time there has been significant development of ladle metallurgy technology [3,4,5], especially in case of metallurgic steel cleanness increase. In relation to that, as a result of less quantity of inclusions, on which partition surface hydrogen is being trapped, steels of very high cleanness are able to trap less hydrogen. When inclusions quantity is decreasing more hydrogen is being gathered on existing inclusions or in different locations where in result cracks occur. Due to that steels of higher metallurgic cleanness are more likely to create strain-hydrogen cracks. Therefore achievements in the field of steel cleanness improvements, as a result of using modern ladle metallurgy brought back to live practically nearly solved problem of hydrogen cracks in forgings.

Within this thesis description and analyze of issues connected with actions designed for decrease of hydrogen content in steel at Steel Melting Shop of Forged Product Plant of Celsa Huta Ostrowiec Sp. z o.o. have been done.

2. Characteristics of Steel Melting Shop of Forged Product Plant of CELSA "Huta Ostrowiec" Sp. z o.o.

Steel melting process at Forged Product Plant of CELSA "Huta Ostrowiec" Sp. z o.o. includes steel melting in Electric Arc Furnace of EBT type, refining in ladle, vacuum degassing and bottom casting of steel into moulds. (fig. 2). Charge to be set depending on steel

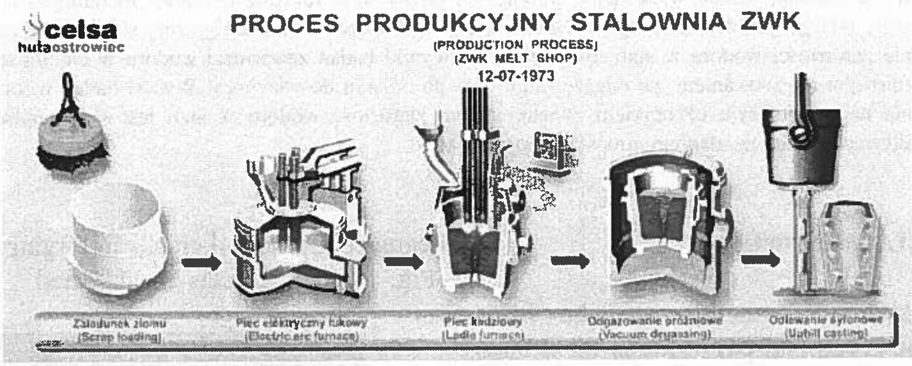

Fig. 2. Manufacturing process of heavy ingots at Steel Melting Shop of FPP CELSA "Huta Ostrowiec" Sp. z o.o.[6]

grade as a combination of low-carbon scrap and alloy steel scrap with addition of carbon, scale and lime. Before the charge is melted blowing of oxygen and material used for foaming the slag is done. On the final step of steel refining difficult soluble ferroalloys are added (Ni, Mo). Slag-forming mixture and most of ferroalloys are to be added to the ladle before tapping. Aluminum and milled carbon to be added on the stream. Tapping is carried out with separation of furnace slag. During refining process in ladle argon is used for continuous blowing through out gas-permeable plug placed at the bottom of the ladle. Chemical composition is being supplemented and deoxydation carried out with additions of granulated aluminum. Anthracite, silicon carbide and carbide is used for slag deoxidation. When refining in ladle is complete and slag is taken off the surface of liquid metal, vacuum degassing of the steel is carried out in vacuum chamber. Later steel is casted by bottom method to moulds of formats from 3 Mg up to 110 Mg (fig. 3).

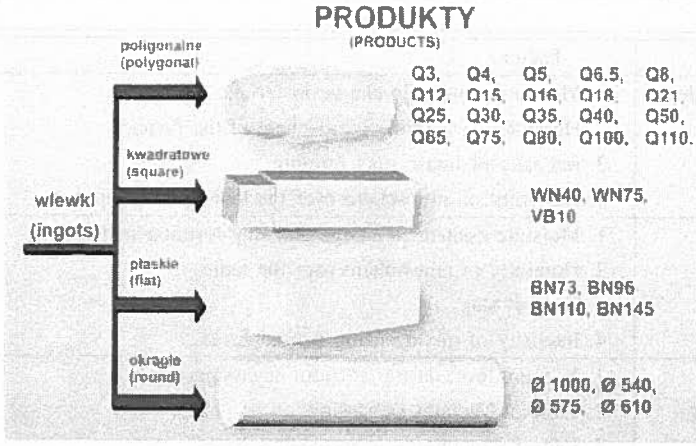

Fig. 3. Products of Steel Melting Shop of FPP CELSA "Huta Ostrowiec" Sp. z o.o.

Steel Melting Shop technical fittings:

a. Electric Arc Furnace of EBT type with capacity of 75 tons,

- with bottom eccentric tapping hole, walls and vault cooled with water,
- power supplied with transformer of 25 MVA power,
- primary voltage 110 KV, secondary voltage 20 KV,

Furnace equipped with:

- manipulator of oxygen blowing lance, milled carbon and lime lances,
- graphite electrodes of diameter Ø 550mm are used,
- melting time 120 minutes.

b. Ladle Furnace with capacity of 65 tons,

- power supplied with transformer of 25 MVA power, item [–] speed of heating steel in the ladle is approximately 3 degrees per minute,
- graphite electrodes with diameter Ø 300 mm,
- a tool for ferroalloys addition,
- time of ladle treatment approximately 60 minutes,

c. Equipment used for inserting aluminum wire and core wire into liquid steel inside the ladle,

d . Ladle Vacuum Degassing system placed in vacuum chamber (achieved vacuum level 0,5 Tor)

- steel degassing is carried out with surface method by mixing the liquid steel using argon (process time approximately 30 minutes), argon supplied by gas-permeable plug placed at the bottom of the ladle.
- hydrogen content in liquid steel is being checked by HYDRIS apparatus,

e. Casting equipment for pouring ingots:

- polygonal ingots for Forging Division, weight range from Q3 to Q 110 tons,
- for Rolling Mill (flat from BN73 to BN145 and squared WN40, WN75, VB10)
- round ingots Ø540, Ø575, Ø610, Ø1000 mm with height 4 m.

Technical fitting of Steel Melting Shop in case of tools for ladle metallurgy allows manufacturing of wide range of steel grades, starting from carbon steel grades to medium-alloy steels. The Shop produces forging ingots for Press Shop needs, forging ingots and rolling mill ingots for sale. All ingots are poured by bottom casting method using argon cover of liquid steel stream. Refractories of LWB company and melting powders of Metallurgica and Intocast companies are used during ingots casting processes.

3. Processes lowering hydrogen content in liquid steel carried out at Steel Melting Shop of FPP Celsa "Huta Ostrowiec" Sp. z o.o.

During technical processes of steel melting, refining and casting there are two opposite effects, hydrogenation of liquid steel and than dehydrogenation of the steel. Hydrogen is absorbed by liquid steel from steam from the atmosphere according to below reaction:

$$H_2O = 2[H] + [O]$$

Table 1 contains main factors which influence hydrogen content on each step of steel melting process.

TABLE 1

Most important factors which influence hydrogen content on each step of steel melting process [3,4,7]

Lp.	Step	Factor
1	Steel melting	1. Moisture content in charge materials. 2. Humidity of working atmosphere of the furnace. 3. Intensity of liquid steel refining. 4. Humidity of atmosphere over the ladle during tapping.
2	Refining	1. Moisture content in charge and slag-forming materials. 2. Humidity of atmosphere over the ladle. 3. Type of slag. 4. Intensity of mixing using neutral gases.
3	Vacuum Degassing	1. Vacuum level during vacuum degassing. 2. Time of Vacuum Degassing. 3. Intensity of mixing using neutral gases. 4. Slag leftover level.
4	Steel casting	1. Humidity of atmosphere over the ladle. 2. Efficiency of liquid steel surface cover made of isolating powder. 3. Efficiency of liquid steel stream cover during casting. 4. Efficiency of liquid steel cover using argon and lubricating powder in mould. 5. Insufficiently heated bottom pouring system. 6. Moisture content of used powders.

Basing on our observations we can state that factors influencing hydrogen content during melting and out of furnace refining have no significant effect on result achieved after vacuum degassing. Due to that, subject thesis focuses only on factors which have effect on hydrogen content during vacuum degassing and steel casting in circumstances of FPP CELSA "Huta Ostrowiec" Sp. z o.o. Actions which aim was to reduce hydrogen level in steel were gathered below:

1. In order to achieve low level of hydrogen after degassing it is necessary to establish certain parameters of Vacuum Degassing process. All vacuum facilities has leakage through which moist air is getting inside the system. Due to that it is impossible to remove whole hydrogen out of steel. During subject work leakage of the vacuum system has been improved so that currently better level of vacuum is being achieved (0,5 Tor) comparing to the vacuum level achieved before repair (0,60 Tor). Besides thanks to actions taken the time of achieving deep vacuum below 1 Tor has been shorten (from 15 to 5 min.). Optimal argon supplying conditions, from reducing level of hydrogen and possibilities of edges splashing with liquid steel point of view, were set (pressure and flow).

2. In order to reduce the problem of absorbing hydrogen from powders, procedures of continuous supervision of moisture content in used powders was introduced. Improvement of powders quality in case of H_2O content allowed to achieve better protection of metal surface in the ladle and in the mould (the less humidity the better powder flows over surface of liquid steel).

3. Proper covers are used during bottom casting process to reduce problem of in-blowing air in the area between ladle and center runner to bottom casting system. A few types of liquid steel stream covers were tested at Steel Melting Shop of FPP (see fig. 4) in case of ceramic covers (fig. 4 a and b) there is a difficulty in sealing the area between center runner and ladle due to possibility of cover or runner damage during ladle descent. This problem has been solved by using refractory covers of plug with glass wool taped on one side (fig. 4 c). both sides taped glass wool has been used for sealing the area between ladle and runner (fig. 4 d). There is a separate problem of supplying with argon and its' volume. The volume of argon supplied during casting should ensure its' overpressure in the system what additionally eliminates possibility of contact with air. Practice shows that argon should be supplied evenly around the stream in order to avoid any possibility of in-blowing air from surroundings. The best solution is to provide argon in opposite direction to metal flowing, so called counter-current, what additionally better protects the stream. However, the difficulties are connected with ensuring even flow of argon around the stream of liquid steel what requires additional improvement of those covers.

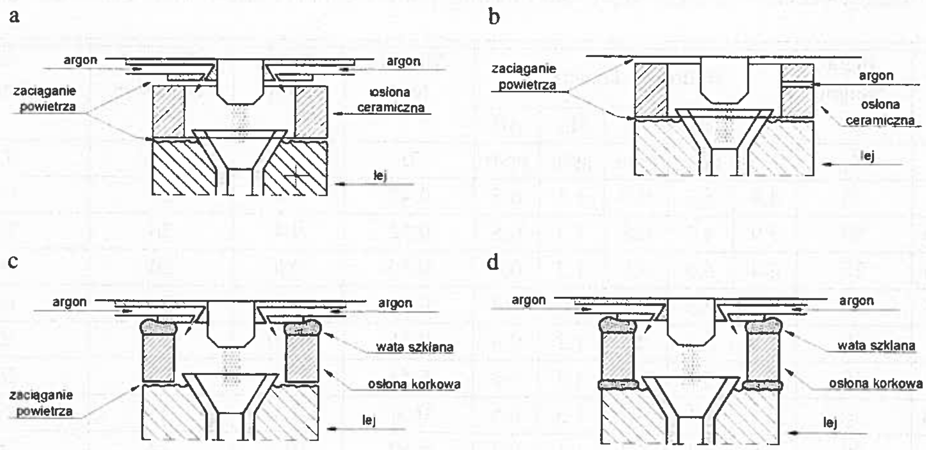

Fig. 4. Types of liquid steel stream covers during bottom casting process:
a – ceramic cover with upper argon supply;
b – ceramic cover with on-side argon supply;
c – cork cover with glass wool on one side and upper argon supply;
d – cork cover with glass wool on both sides and upper argon supply.

5. A separate problem is to eliminate contact between liquid steel and air inside of mould during pouring. In the initial stage there is a stormy metal movement what is favorable for hydrogenation. (fig. 5.). Due to that currently argon is supplied to every mould before casting. To ensure a better sealing of casting system, mould is covered from the top during argon supplying. The cover is removed just before casting process beginning. Furthermore casting equipment is heated up before casting to temperature level 80 – 120°C.

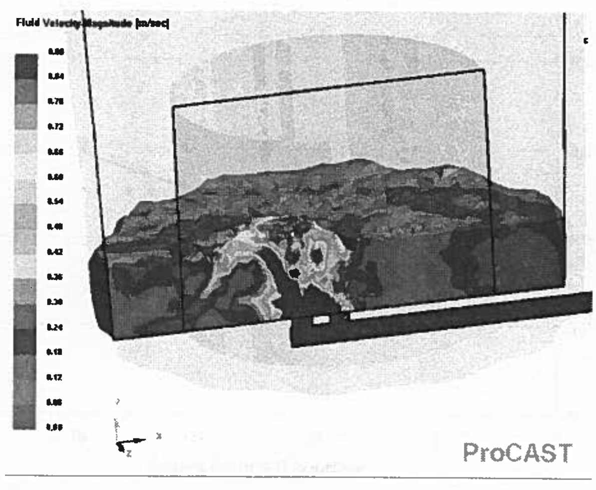

Fig. 5. Casting process of ingot Q25 Mg simulation – speed of metal flow distribution in the first stage

4. Hydrogen content testing results during steel melting process at Forged Product Plant Celsa "Huta Ostrowiec" Sp. z o.o.

Within this thesis number of hydrogen content testing have been carried out on many steps of the process. Test on liquid steel has been done with usage of Hydris tool produced by Electro – Nite company [8]. The investigations of hydrogen content in liquid steel after tapping, before vacuum degassing, after vacuum degassing and after casting to moulds were carried out. Results of testing together with degassing parameters are gathered in table 2.

TABLE 2

Results of hydrogen content on every step of steel melting process at FPP CELSA "Huta Ostrowiec" Sp. z o.o.

Order no	Steel grade	Ingot weight	Hydrogen kontent					Vacuum level	Argon flow	Time of degassing	Air temperature	Relative humidity
			H_A	H_B	H_C	H_D	ΔH					
–	–	Mg	ppm	ppm	ppm	ppm	ppm	Tr	m^3/min	min	°C	%
1	42CrMo4	30	4.9	5.2	0.7	1.2	0.5	0.47	8.8	21	19	78
2	34CrNiMo6	50	3.9	4.2	0.8	1.3	0.5	0.52	9.4	20	23	84
3	34CrNiMo6	25	4.4	5.0	0.9	1.3	0.4	0.50	9.0	20	16	82
4	34CrNiMo6	50	5.1	5.5	0.7	1.0	0.3	0.51	8.8	22	14	42
5	S34MnV	50	5.5	6.1	0.8	1.2	0.4	0.55	10.0	25	30	39
6	HF601	50	5.2	5.6	0.7	1.3	0.6	0.51	10.0	25	28	57
7	34CrNiMo6	30	5.1	5.6	0.7	1.3	0.6	0.51	10.0	25	27	77
8	S34MnV	30	4.8	5.1	0.7	1.1	0.4	0.52	10.2	24	26	60
9	34CrNiMo6	30	4.9	5.3	0.7	1.0	0.3	0.49	9.9	25	16	45
10	CK45	50	4.5	5.1	0.8	1.2	0.4	0.52	12.0	25	24	35
11	S34MnV	50	5.2	5.9	0.8	1.2	0.4	0.48	10.0	22	12	64
12	34CrNiMo6	30	5.5	5.8	0.9	1.3	0.4	0.51	8.3	25	19	50
13	C-Mn	30	5.5	7.2	0.8	1.1	0.3	0.50	10.0	23	4	52
14	34CrNiMo6	30	4.7	5.5	0.7	1.2	0.5	0.45	10.5	24	26	74
15	S34MnV	50	4.9	5.5	0.7	1.3	0.6	0.49	10.0	25	27	47

symbols:
H_A – hydrogen content after tapping from furnace,
H_B – hydrogen content after ferroalloys addition (before degassing),
H_C – hydrogen content after degassing,
H_D – hydrogen content in ingot (liquid steel),
ΔH – increase of hydrogen content during casting

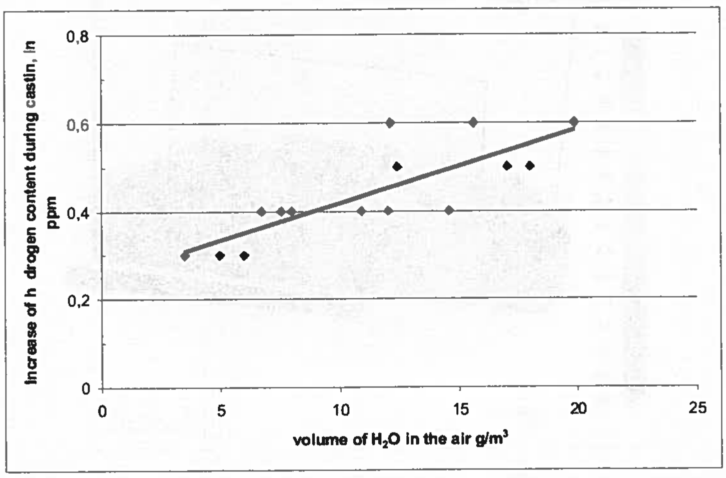

Fig. 6. Hydrogen content increase during casting depending on H_2O content in the air

According to testing carried out in conditions of FPP CELSA "Huta Ostrowiec" Sp. z o.o. comes out that hydrogen content measured after tapping from furnace is within range of 3.9 – 5.5 ppm. Hydrogen is absorbed to steel with charge materials (scrap, slag-forming materials, ferroalloys, etc.). Hydrogenation can happen also during liquid steel contact with working furnace atmosphere which contains steam. Testing carried out just before vacuum degassing proved that from the moment of tapping there is and increase of hydrogen content in range of from 0.3 do 1.7 ppm. This increase of hydrogen level in liquid steel can be connected with absorbing hydrogen from atmosphere and moistured alloys and slag-forming additions. In result of vacuum degassing hydrogen content of level 0.7 – 0.9 ppm is achieved. The level of hydrogen increases with 0.3 – 0.6 ppm again during casting and achieves level of 1.0 – 1.3 ppm.

Steam volume in the air influences volume of hydrogen absorbed during casting. Maximum humidity, so maximum volume of steam in certain volume of air depends strongly on air temperature. The higher is the temperature the more steam contains the air. Due to above during casting steel in days of hot and humidity hydrogen level increases much more than during cold and dry days (fig. 6).

In addition for ingot marked with number 4 testing of hydrogen content in solid state on forged sample parts Ø900 were carried out. The sample placement in the ingot with results of testing are shown in fig 7. Hydrogen content in steel was done by automatic analisator H-mat 2500. During measurement hydrogen was extracted by annealing solid steel samples to temperature 900°C in tilting furnace in neutral gas stream. Due to the fact that test was done in specialized, external laboratory so samples were frozen in CO_2 immediately after cutting off in order to eliminate risk of hydrogen reaction with oxygen. Presented figure shows that there is a significant segregation of hydrogen in the volume of ingot. Differences of hydrogen content come out from the fact that hydrogen is pushed by crystallization to places where solidification process happens latest. Besides some influence on differences of hydrogen level in cross section can have changes during solidification process. Results may be lower than results achieved for ingot (which indicated 1.2 ppm H_2) due to the fact that certain volume of hydrogen diffuses from samples during preparation. Furthermore some differences may come out of different methods of hydrogen content checking used. However, testing on solid samples showed that during solidification hydrogen segregates in direction of top of the ingot. Risk of strain-hydrogen cracks in forging made of that part of ingot increases.

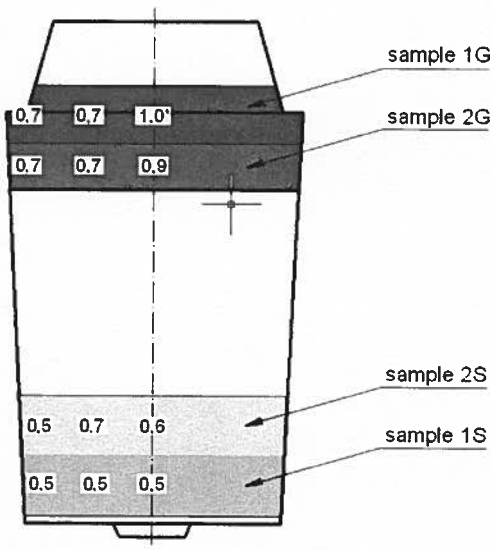

Fig. 7. Results of hydrogen content testing for ingot Q 50 tons

5. Summary and conclusions

This thesis shows description and analyze of issues connected with activities which aim is to lower hydrogen content in steel manufactured in Forged Product Plant CELSA "Huta Ostrowiec" Sp. z o.o. Currently in our plant the problem of strain-hydrogen cracks of forgings does not exist. However increasing requirements of our customers concerning steel cleanness may result in reactivating the problem. Due to that improvement of metallurgic steel cleanness must be parallel to decrease of hydrogen content.

According to tests carried out on further steps of steel melting process it comes out that besides vacuum degassing the most important factor influencing hydrogen content in ingots is effectiveness of liquid steel protection during casting to moulds to avoid re-hydrogenation. Due to that in the nearest future we plan following actions aiming further lowering hydrogen level in ingots manufactured at Forged Product Plant CELSA "Huta Ostrowiec" Sp. z o.o:

- Purchase of new equipment for vacuum degassing of steel
- Modification of liquid steel stream cover during casting
- Change of bottom pouring system channels shape through which metal flows to mould (based on virtual simulation)
- Purchase of equipment for hydrogen content testing on samples taken from ingots immediately after casting.

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