Presence of shrinkage porosity in the casting of a LUK single mass flywheel

L-030204-0H53-06-000 of material EN GJL 250

Kočevar Robert

Date, 12.2.2024

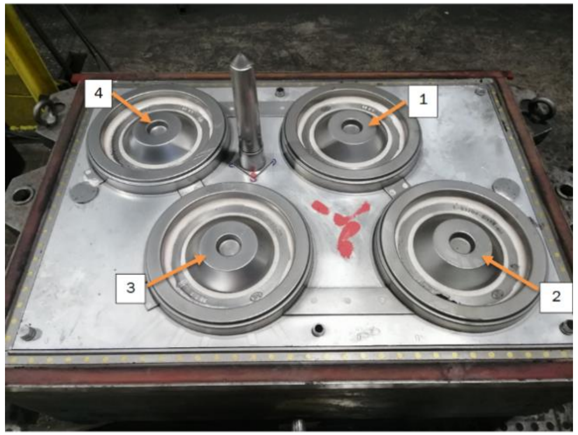
Contents of the shrinkage porosity presentation

- Product description
- Scrap trends since the start of production
- Tightening of quality criteria after machining of castings
- Display of analyses:
  - Melt control by ATAS MetStar (Advance Thermal Analysis System)
  - Control of the sand mixture with the "Green sand control - Belloi & Romagnoli" device
  - Tests with modified casting system
  - Tests with modified feeding system
- Description of the solution with exothermic feeders
- Conclusion

Product description

Material: EN GJL 250 and bentonite sand mix for mould making

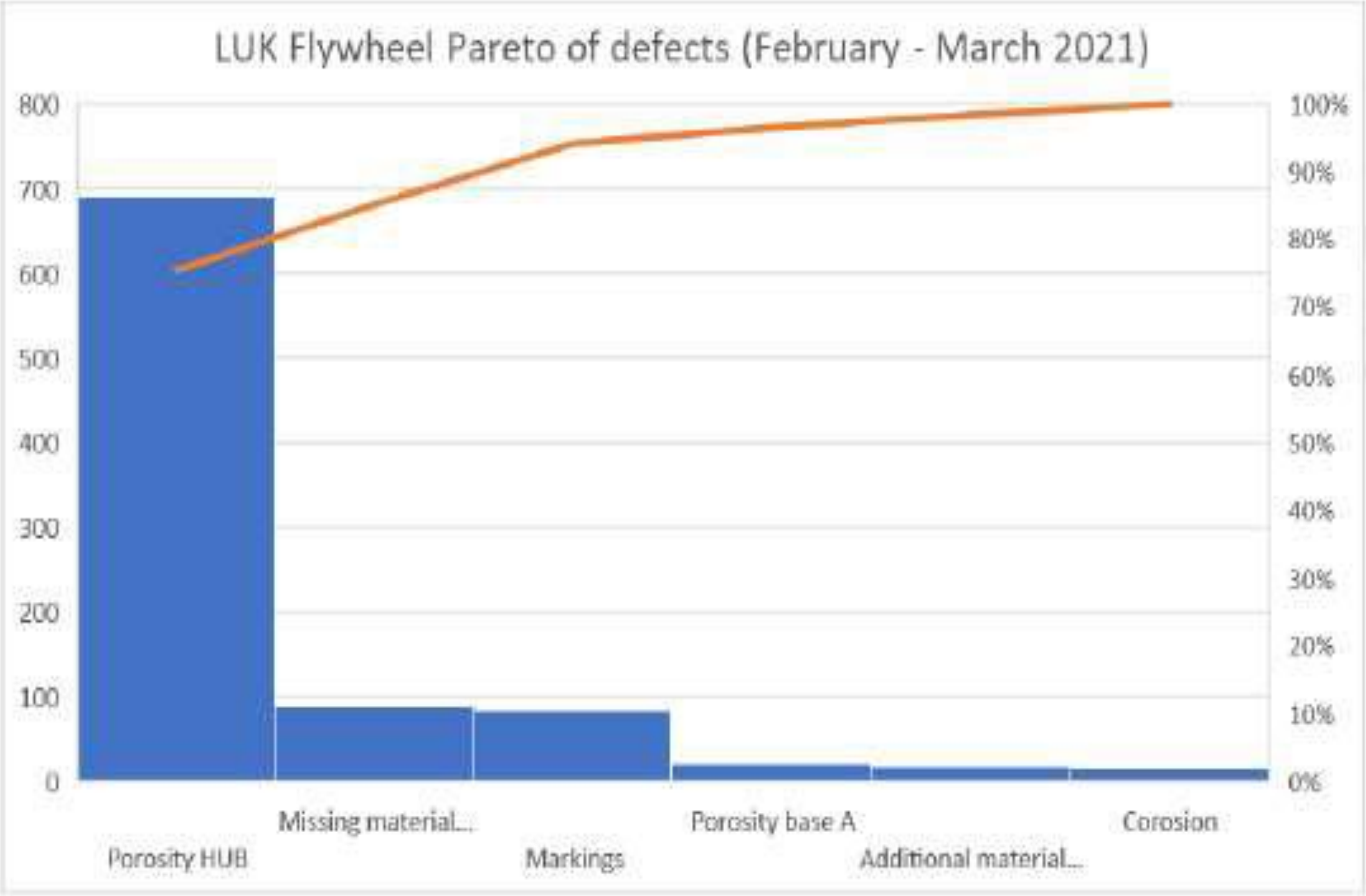
Brutto weight ……..18,700 kg   Netto weight ………15,450 kg





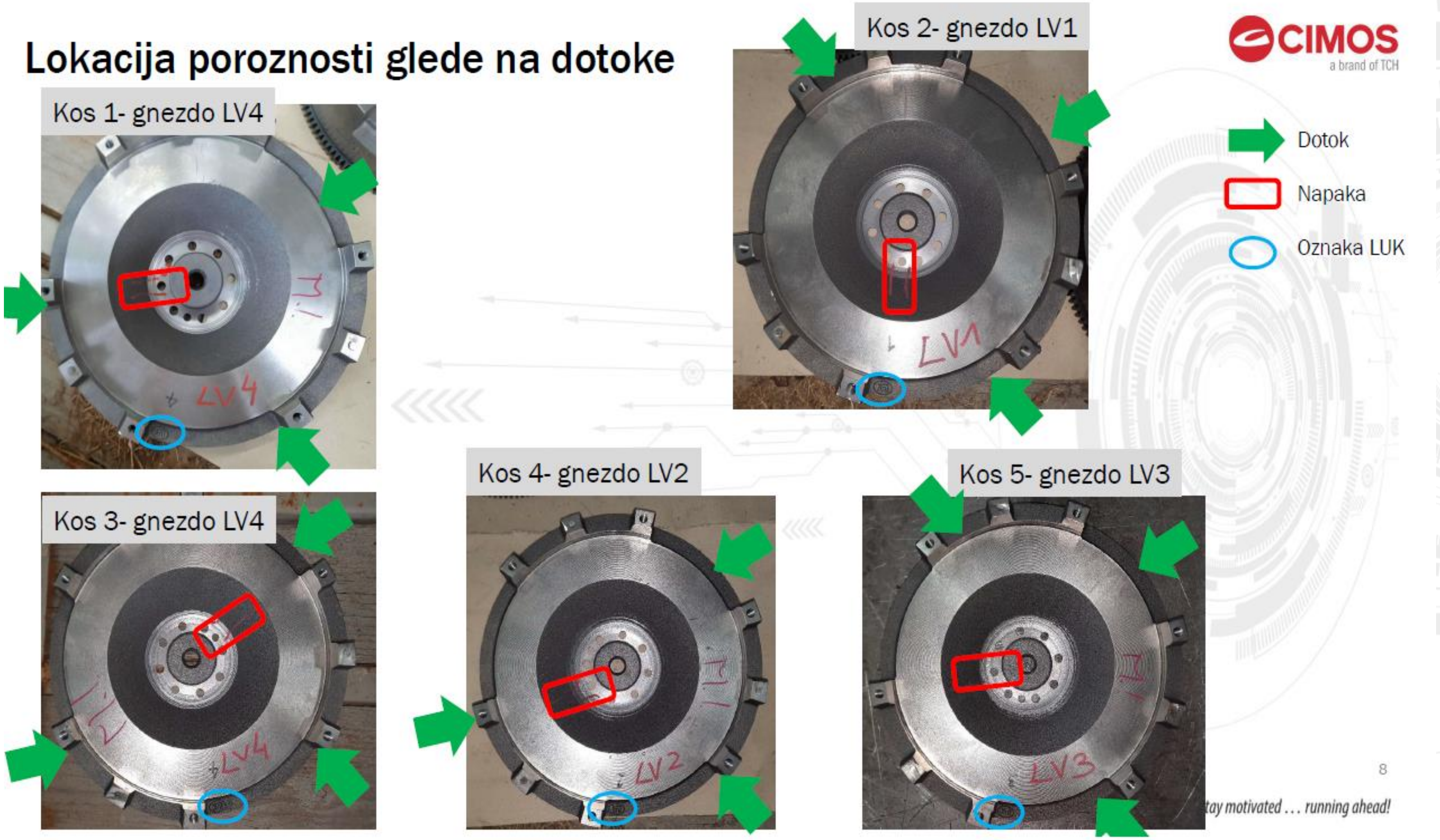
Main defect after mechanical treatment

The main defect after machining is shrinkage porosity:



Main defect: Porosity on hub

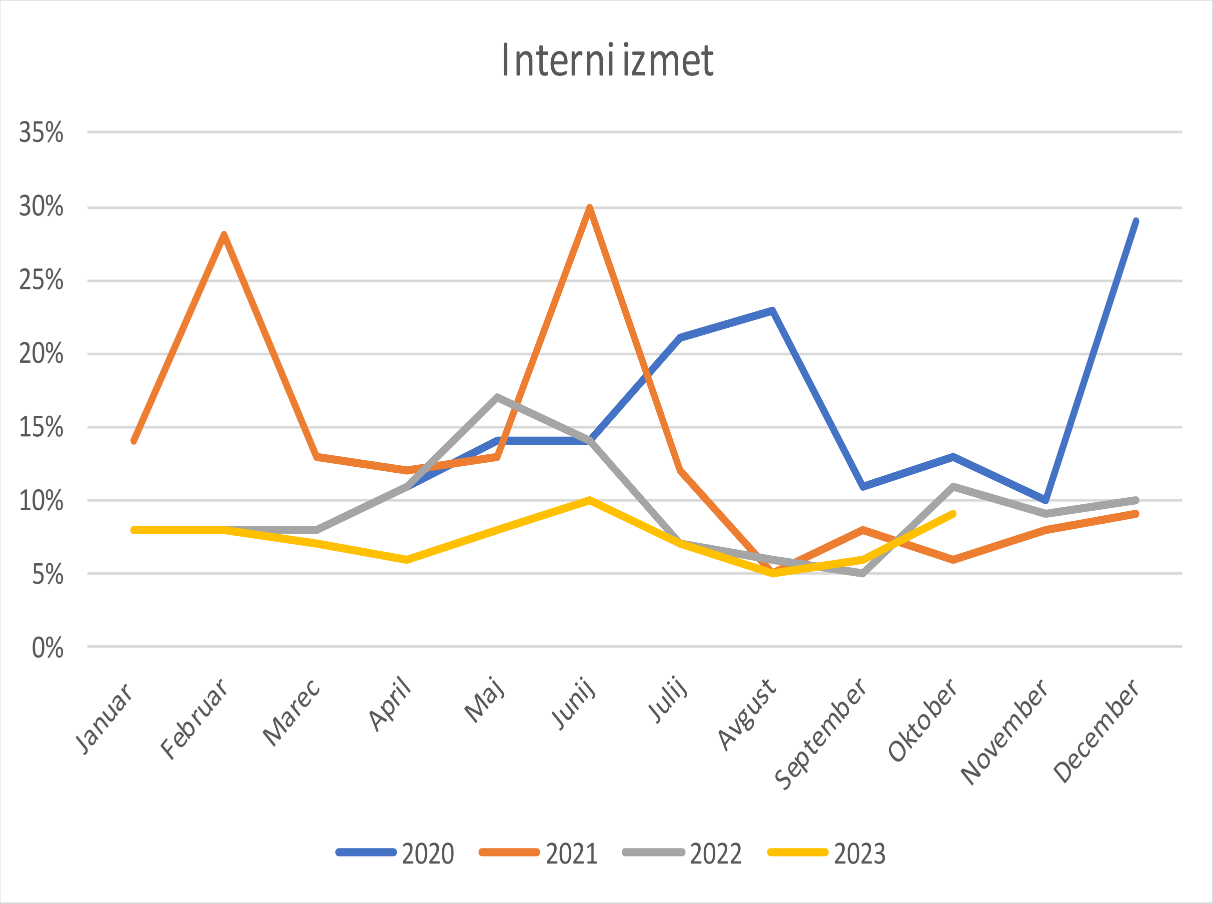
Location of shrinkage porosity in relation to the attachment of the casting ingates



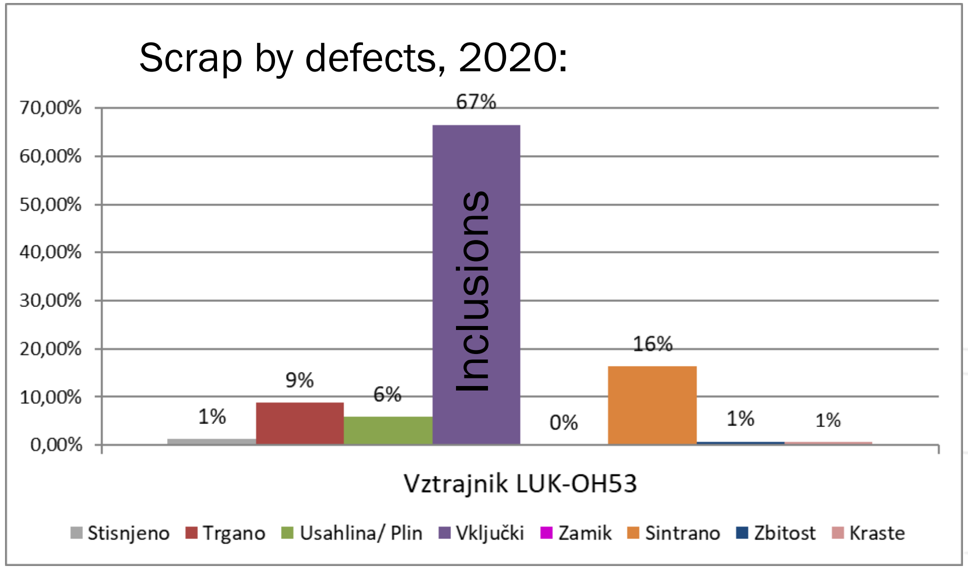
Evolution of internal scrap since the start of production

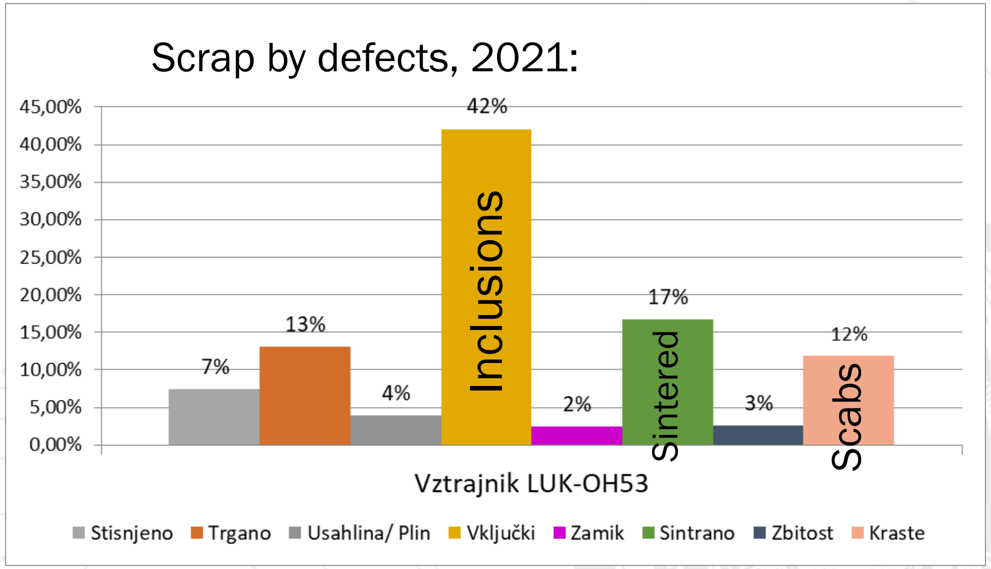
Internal scrap from April 2020 till 2023:

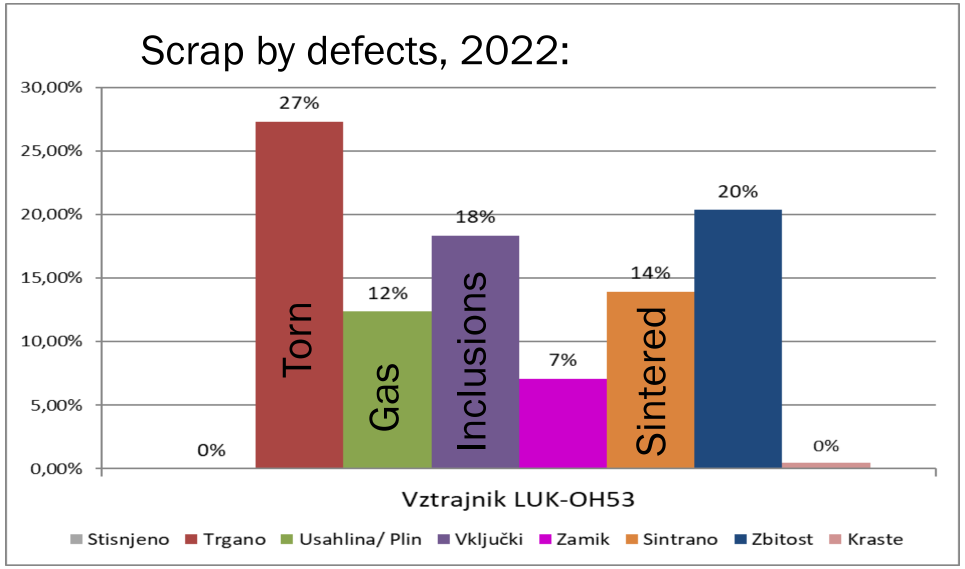
	2020	2021	2022	2023
Januar		14%	8%	8%
Februar		28%	8%	8%
Marec		13%	8%	7%
April	11%	12%	11%	6%
Maj	14%	13%	17%	8%
Junij	14%	30%	14%	10%
Julij	21%	12%	7%	7%
Avgust	23%	5%	6%	5%
September	11%	8%	5%	6%
Oktober	13%	6%	11%	9%
November	10%	8%	9%	
December	29%	9%	10%	

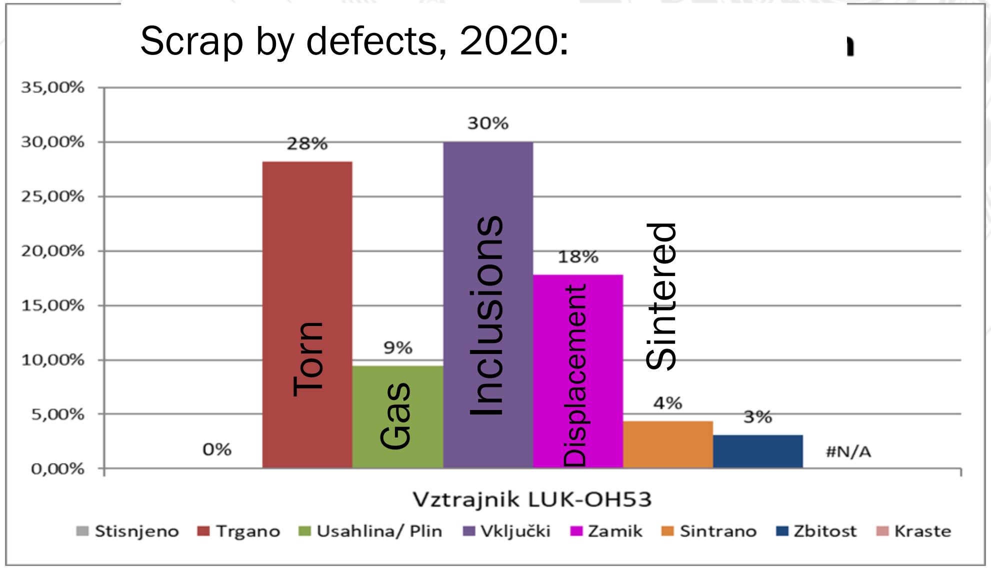


Analysis of internal scrap by fault for 2020-2023



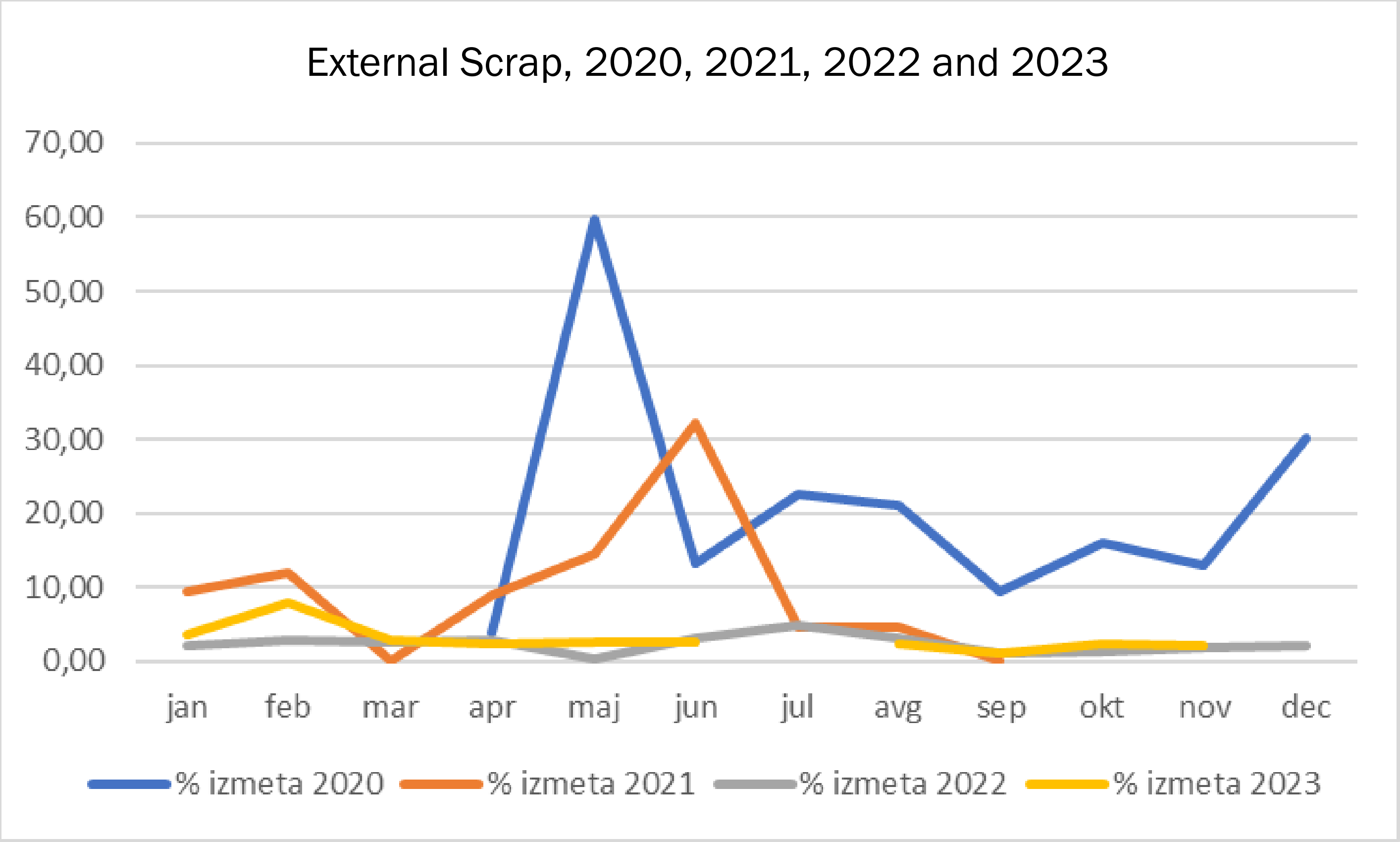






Evolution of the external scrap since the start of production

	jan	feb	mar	apr	maj	jun	jul	avg	sep	okt	nov	dec
% izmeta 2020				3,82	59,86	13,16	22,44	21,11	9,46	15,87	12,94	30,26
% izmeta 2021	9,36	11,97	0,00	9,00	14,53	32,05	4,69	4,63	0,02			
% izmeta 2022	2,07	2,82	2,64	2,85	0,19	2,96	4,80	3,15	1,14	1,32	1,71	2,08
% izmeta 2023	3,69	7,77	2,87	2,25	2,64	2,68		2,35	0,98	2,21	1,99	

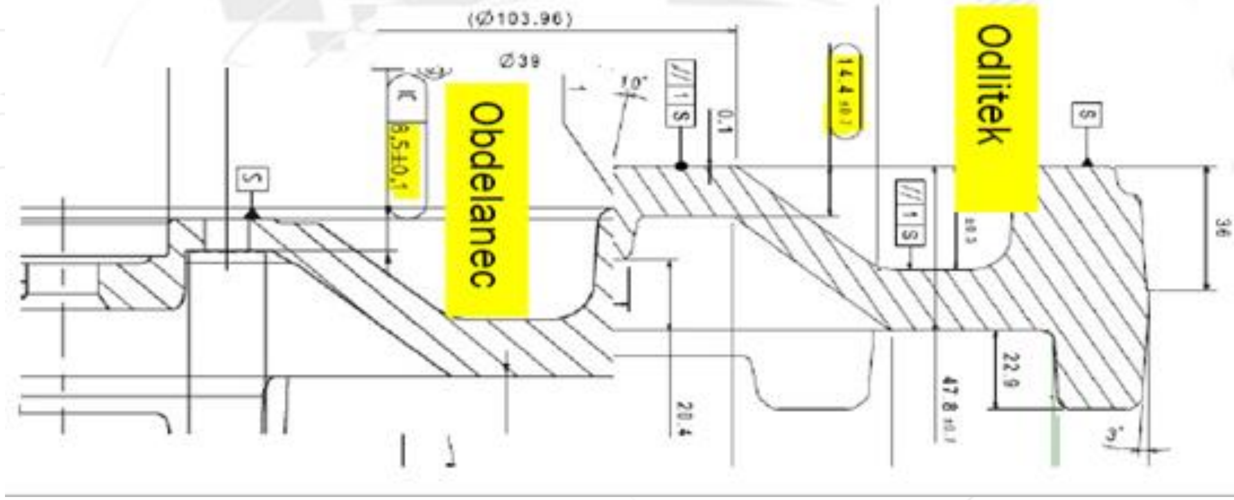


Size of shrinkage porosity

- The variation in quality or material ejection is due to the tightening of the shrinkage porosity criteria also in the depth of the casting or throughout the cross-section, which only becomes apparent after machining. The shrinkage porosity is mainly due to the unfavourable design of the casting, which cannot be compensated for even by the good self-feeding properties of grey cast iron:

- 5 postruženih kos
- Poroznost sega v globino do 4,5mm po površini pa do 14,5mm
- Poroznost se začne med 0,5mm in 1,5mm v globini že obdelanega kosa
- V primerjavi z odlitkom je poroznost prisotna na 31% dimenzije debeline stene glede na nominalno dimenzijo (14,4mm).
- Na obdelani površini pa 53% dimenzije debeline stene glede na nominalno dimenzijo (8,5mm).

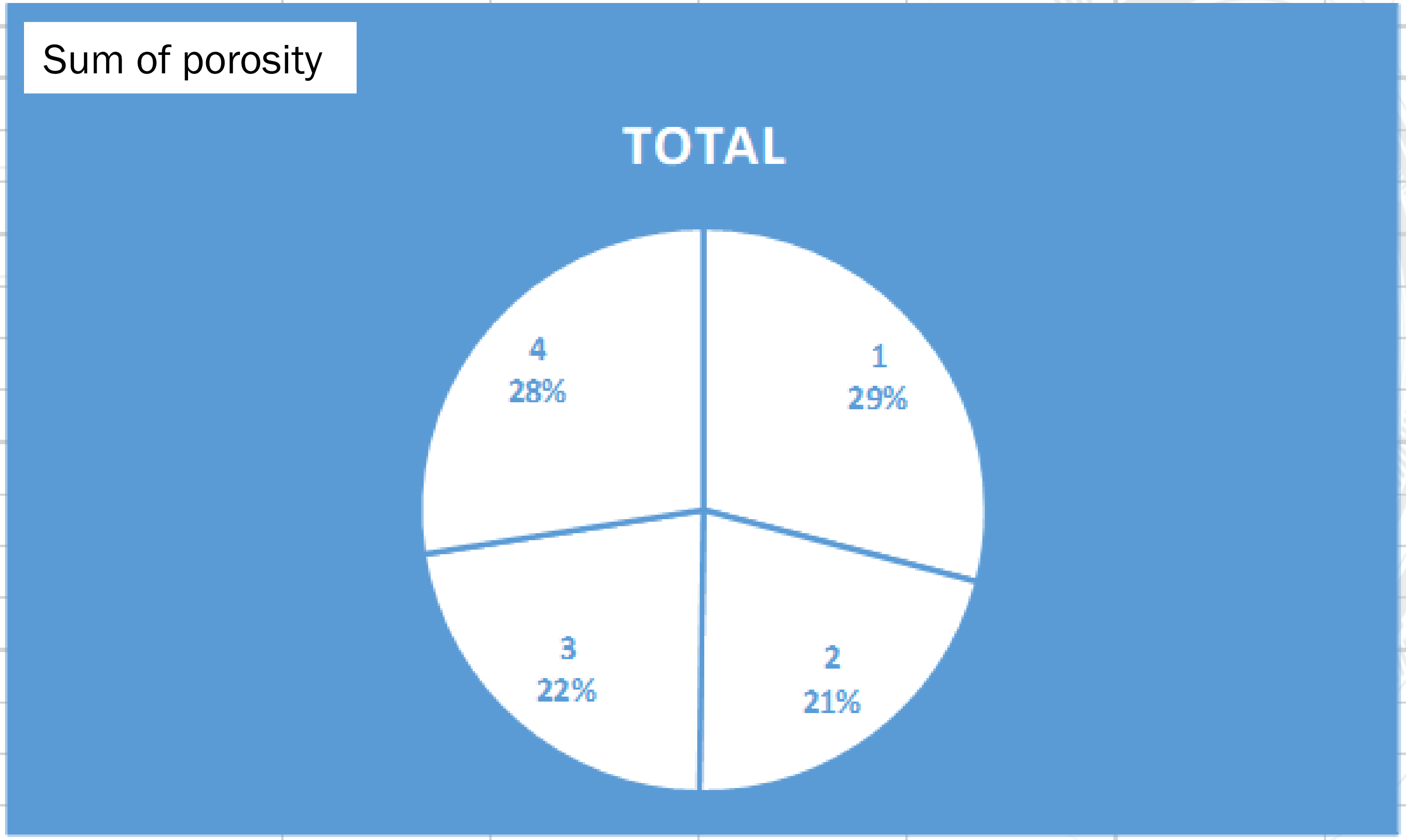
#	Gnezdo	Začetek poroznosti [mm]	Konec poroznosti [mm]	Globina max poroznosti [mm]	Max širina poroznosti [mm]	Skupna globina poroznosti [mm]
1	LV4	1,0	5,0	2,0	11,4	4,0
2	LV1	0,5	5,0	0,5	13,8	4,5
3	LV4	0,5	5,0	0,5	14,5	4,5
4	LV2	1,5	5,5	1,5	12,5	4,0
5	LV3	1,0	4,5	2,0	9,6	3,5
	max.	1,5	5,5	2,0	14,5	4,5
	min.	0,5	4,5	0,5	9,6	3,5



Shrinkage porosity vs. engraving position

- Analysis of the material external scrap - porosity vs. engraving number:

Location	Sum of porosity
1	201
2	146
3	154
4	190
Grand Total	**691**



Shrinkage porosity on hub

CIMOS

- Fishbon

CAUSES

	MAN		METHOD		ENVIRONMENT
1	Respect of the work instructions	1	Chemical composition not well defined	1	Ambient temperature alternations
2	Not properly trained operators (skill matrix)	2	Composition of raw material for melting not well defined	2	Wet/dry basic material, due to conditions on transport
3		3	Unsuficiend feeding of hot spot	3	
4		4	Hardness of mould may affect on shrinkage porosity on product	4	
5		5	Pouring after 10min of breakdown on the line	5	
6		6	Sistemic defect on cavity number	6	
7		7	Sand composition- green sand properties	7	
8		8		8	

	MEASUREMENT		MACHINE		MATERIAL
1	Metalografic structure variation	1	Differences between melting furnaces.	1	Basic material with presence of rust and other impurities
2	No method for early discovery of defects (hidden defect)	2	Inoculation into the stream	2	Availability of prescribed materials (stamp sheet matal) and PIG iron
3	Correlation of parameters and material scrap	3	GSC measuring system - green sand preparation	3	Condition of raw material proper quality (dust)
4	NOK measurements of chemical composition	4	Compacting mould pressure	4	Foundry returning/circular material
5		5	Pattern T	5	Sand composition- green sand properties
6		6		6	Chemical composition not respected
7		7		7	
8		8		8	

DEFECT
Porosity on hub

Optimising raw materials for the production of the LUK flywheel casting

- ❑ Tightening the criteria for the stabilityraw material for the production of melt:

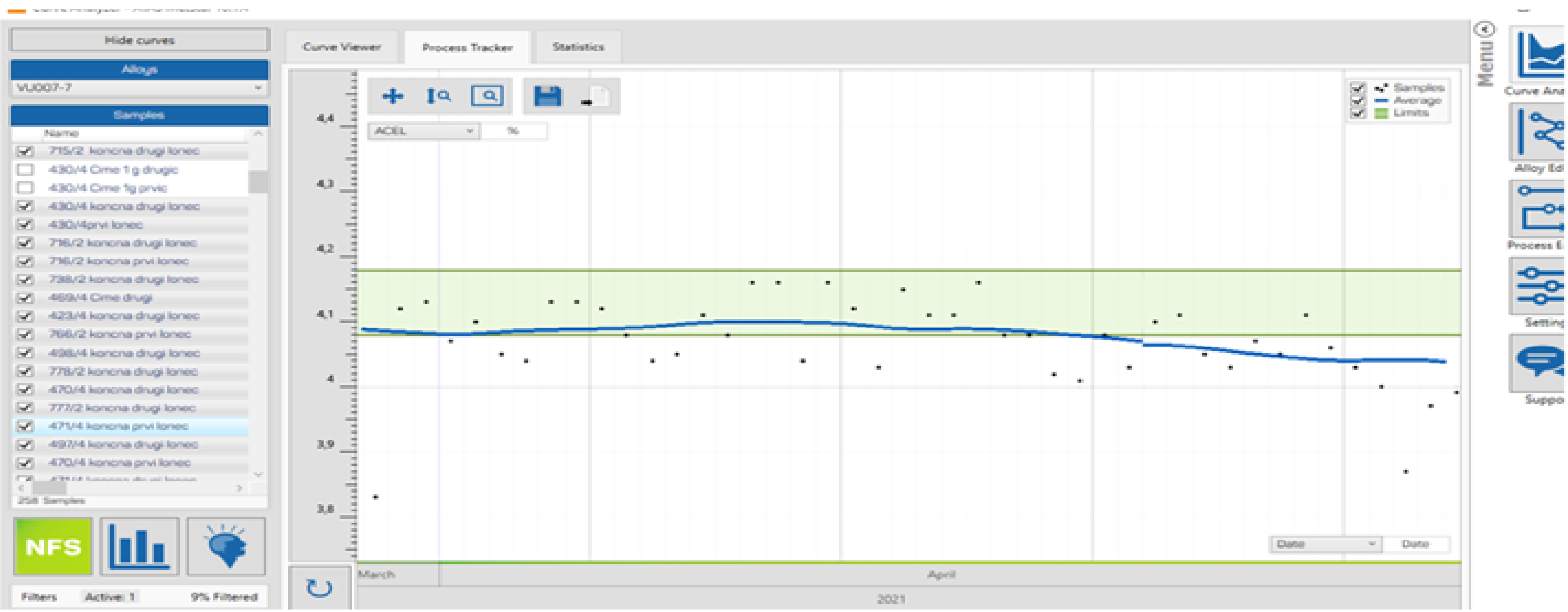
- ➢ Before optimisation

- ➢ After optimisation

Melt control by ATAS MetStar

- Melt control by ATAS MetStar and analysis of the results in correlation with the material scrap after each batch of casting after machining

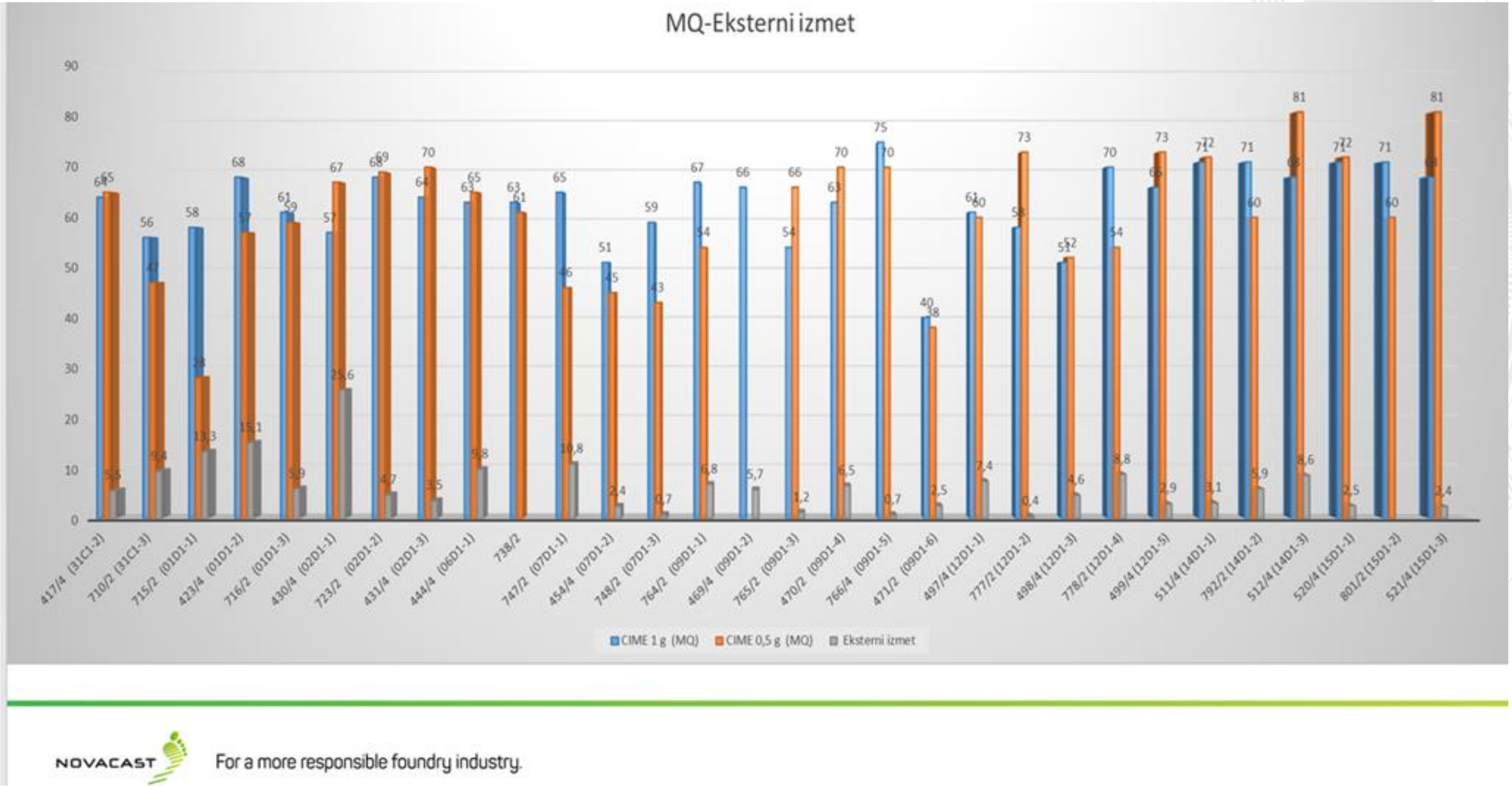
ACEL parameter for first and second ladle depended on time (VU007-7)



As we see on a figure above, ACEL oz (CEL) moves downwards from middle of the april.

Melt control by ATAS MetStar

- The relationship between MQ and external scrap is directly correlated with R, GRF1 and GRF2 according to ATAS MetStar analyses, or these parameters have twice the significance compared to TL, TL low and TS.

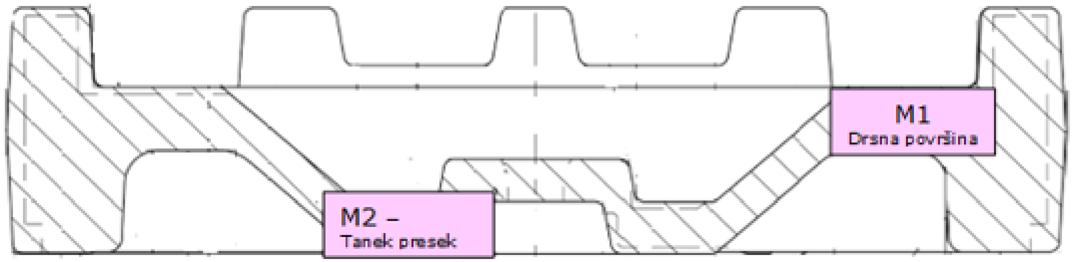


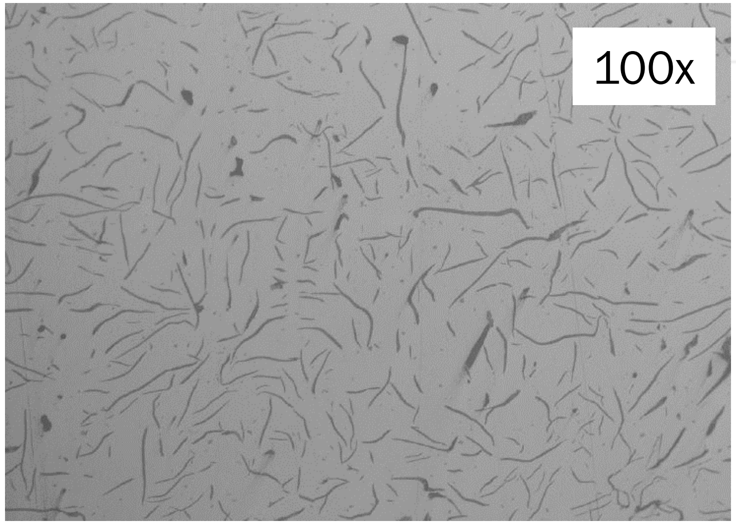
Melt control by ATAS MetStar

Microstructural comparison of flywhell LUK, surface M1:

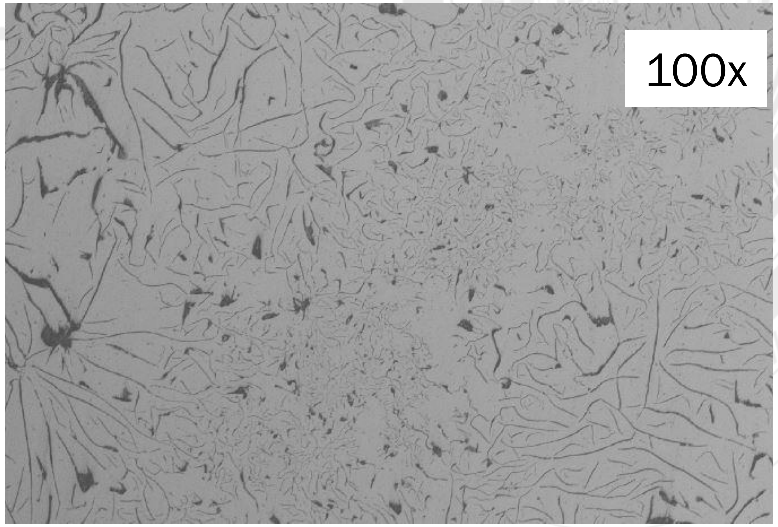
Low scrap (good quality):

High scrap (bad quality):





Graphite shape A



Large graphite flakes with combined undercooled graphite

Size and shape of the graphite are directly connected to the ATAS MetStar thermal parameters (next slide).

Melt control by ATAS MetStar

CIMOS

Statistical comparison between good and bad iron for LUK (VU007-7)

Low scrap (good quality):

Statistics

Property	Average	Min	Max	Std. Dev.	Multiplier	Lower Adjustment	Upper Adjustment
TL	1169,1	1155,7	1193,0	13,3	3,5	1169,2 (-46,7 → 1122,5)	1184,2 (31,5 → 1215,7)
TELow	1135,5	1134,1	1140,3	2,4	3,5	1135,9 (-8,8 → 1127,1)	1142,9 (1,0 → 1143,9)
TEHigh	1141,8	1139,4	1146,8	2,7	3,5	1139,9 (-7,5 → 1132,4)	1146,9 (4,3 → 1151,2)
TS	1094,9	1090,2	1102,5	4,2	3,5	1100,0 (-19,8 → 1080,2)	1125,0 (-15,4 → 1109,6)
TES	1159,7	1150,1	1176,9	10,2	3,5	1152,5 (-28,5 → 1124,0)	1163,5 (31,9 → 1195,4)
R	6,3	5,2	7,7	0,9	3,5	2,5 (0,7 → 3,2)	6,0 (3,4 → 9,4)
GRF1	65	60	70	4	3,5	60 (-9 → 51)	90 (-11 → 79)
GRF2	44	32	61	10	3,5	15 (-6 → 9)	45 (34 → 79)
S1	34,3	28,4	43,1	5,1	3,5	28,8 (-12,4 → 16,4)	52,0 (0,2 → 52,2)
TSDer	-2,92	-3,28	-2,52	0,27	3,5	-4,00 (0,13 → -3,87)	-2,50 (0,52 → -1,98)
TESDer	-0,84			0,17	3,5	-2,00	0,00

High scrap (bad quality):

Statistics

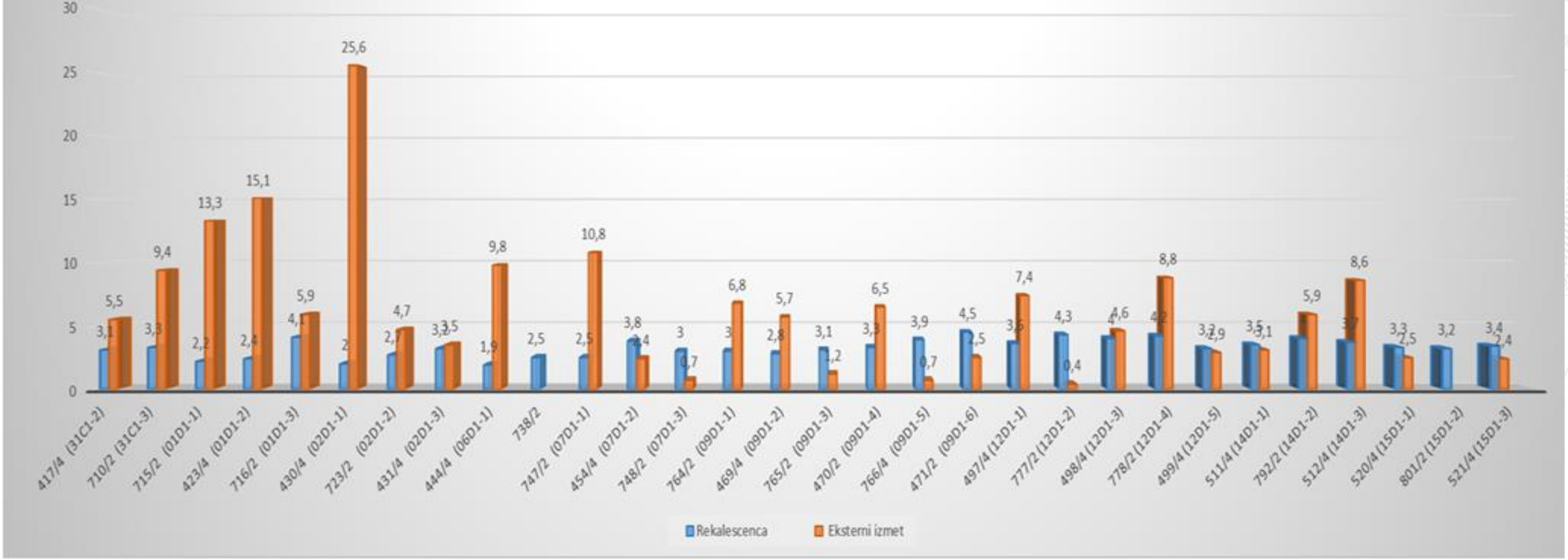
Property	Average	Min	Max	Std. Dev.	Multiplier	Lower Adjustment	Upper Adjustment
TL	1166,4	1157,4	1177,6	6,9	3,5	1169,2 (-27,0 → 1142,2)	1184,2 (6,4 → 1190,6)
TELow	1135,9	1131,8	1137,7	1,9	3,5	1135,9 (-6,7 → 1129,2)	1142,9 (-0,3 → 1142,6)
TEHigh	1143,8	1139,1	1146,1	2,4	3,5	1139,9 (-4,5 → 1135,4)	1146,9 (5,3 → 1152,2)
TS	1094,2	1086,0	1097,7	4,2	3,5	1100,0 (-20,5 → 1079,5)	1125,0 (-16,1 → 1108,9)
TES	1155,2	1150,3	1160,9	3,5	3,5	1152,5 (-9,6 → 1142,9)	1163,5 (3,9 → 1167,4)
R	7,8	6,1	8,9	1,0	3,5	2,5 (1,8 → 4,3)	6,0 (5,3 → 11,3)
GRF1	61	58	64	2	3,5	60 (-6 → 54)	90 (-22 → 68)
GRF2	53	41	67	9	3,5	15 (7 → 22)	45 (39 → 84)
S1	31,4	26,6	37,8	3,9	3,5	28,8 (-11,0 → 17,8)	52,0 (-7,0 → 45,0)
TSDer	-2,67	-2,98	-2,43	0,18	3,5	-4,00 (0,70 → -3,30)	-2,50 (0,46 → -2,04)
TESDer	-0,90			0,06	3,5	-2,00	0,00

Above comparison shows that thermal parameters such as R, GRF1 and GRF2 have largest average differences between good and bad quality, which gives indication about importance of these three parameters for early prediction of scrap.

Melt control by ATAS MetStar

- According to the DTA analyses and the results of the material scrap after machining, there is a direct correlation between the minimum recalescence values obtained and the high possibility of increased shrinkage porosity.

Recalescence (blue) vs external scrap (orange)



Conclusions of melt control by ATAS MetStar

To get a good correlation between the ATAS results and the external scrap (shrinkage porosity), we came up with important facts for a good melt quality of type VU007:

a.) R must not be higher than 6 degrees Celsius and not less than 2.5 degrees Celsius.

b.) The GRF1 parameter should be higher than 60

c.) The GRF2 parameter should be less than 45

Limits				
	Min	Mean	Max	
TL	1169,2	1176,7	1184,2	°C
TELow	1135,9	1139,4	1142,9	°C
TEHigh	1139,9	1143,4	1146,9	°C
TS	1100,0	1112,5	1125,0	°C
TES	1152,5	1158,0	1163,5	°C
TEWhite	1113	1116	1119	°C
R	2,0	4,0	6,0	°C
GRF1	60	75	90	
GRF2	15	30	45	
S1	29	40	52	%
dT/dt TS	-4,00	-3,25	-2,50	°C
dT/dt TES	-2,00	-1,00	0,00	°C

Melt inoculation with Foseco MSI 900

CIMOS

220106.TXT - Notepad

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Date/Time          Counter g/sec.  Inoc.Time      HB °C   Failure / Warning / Remark
06.01.2022 00:11:53        7057 125.8 / 123.7        8.5        37.0
06.01.2022 00:12:28        7058 125.8 / 125.0        8.5        37.0
06.01.2022 00:13:08        7059 127.3 / 126.1        8.6        37.0
06.01.2022 00:13:49        7060 125.8 / 124.6        8.5        37.0
06.01.2022 00:14:29        7061 125.8 / 124.9        8.5        37.0
06.01.2022 00:15:09        7062 125.8 / 124.7        8.5        37.0
06.01.2022 00:16:17        7063 127.3 / 126.0        8.6        37.0
06.01.2022 00:17:11        7064 125.8 / 125.0        8.5        37.0
06.01.2022 00:17:52        7065 127.3 / 126.6        8.6        37.0
06.01.2022 00:18:37        7066 125.8 / 125.1        8.5        37.0
06.01.2022 00:20:48        7067 125.8 / 125.2        8.5        37.0
06.01.2022 00:22:13        7068 125.8 / 125.2        8.5        37.0
06.01.2022 00:30:46        7069 125.8 / 125.2        8.5        37.0
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06.01.2022 00:35:30        7075 125.8 / 124.8        8.5        37.0
06.01.2022 00:36:10        7076 170.0 / 170.0        8.5        37.0
06.01.2022 00:50:19        7077 170.0 / 170.0        8.5        37.0
06.01.2022 00:51:23        7078 170.0 / 170.0        8.5        37.0
06.01.2022 00:52:38        7079 170.0 / 170.0        8.5        37.0
06.01.2022 00:53:17        7080 170.0 / 170.0        8.5        37.0
06.01.2022 00:54:32        7081 170.0 / 170.0        8.5        37.0
06.01.2022 00:55:12        7082 170.0 / 170.0        8.5        37.0
06.01.2022 00:55:53        7083 170.0 / 170.0        8.5        37.0
06.01.2022 00:56:32        7084 172.0 / 172.0        8.6        37.0
06.01.2022 00:57:12        7085 170.0 / 170.0        8.5        37.0
06.01.2022 00:57:53        7086 172.0 / 172.0        8.6        37.0
06.01.2022 00:58:32        7087 170.0 / 170.0        8.5        37.0
06.01.2022 00:59:12        7088 170.0 / 170.0        8.5        37.0
06.01.2022 00:59:52        7089 170.0 / 170.0        8.5        37.0
06.01.2022 01:00:33        7090 172.0 / 172.0        8.6        37.0
06.01.2022 01:01:12        7091 170.0 / 170.0        8.5        37.0
06.01.2022 01:01:53        7092 172.0 / 172.0        8.6        37.0
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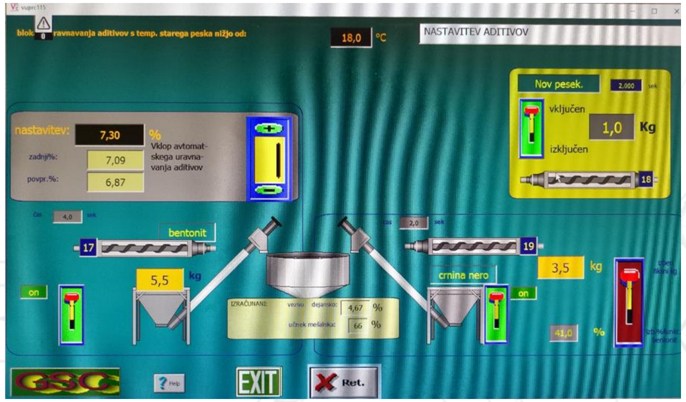
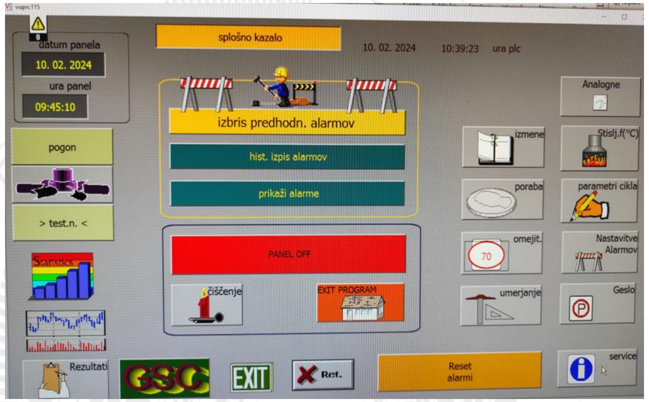
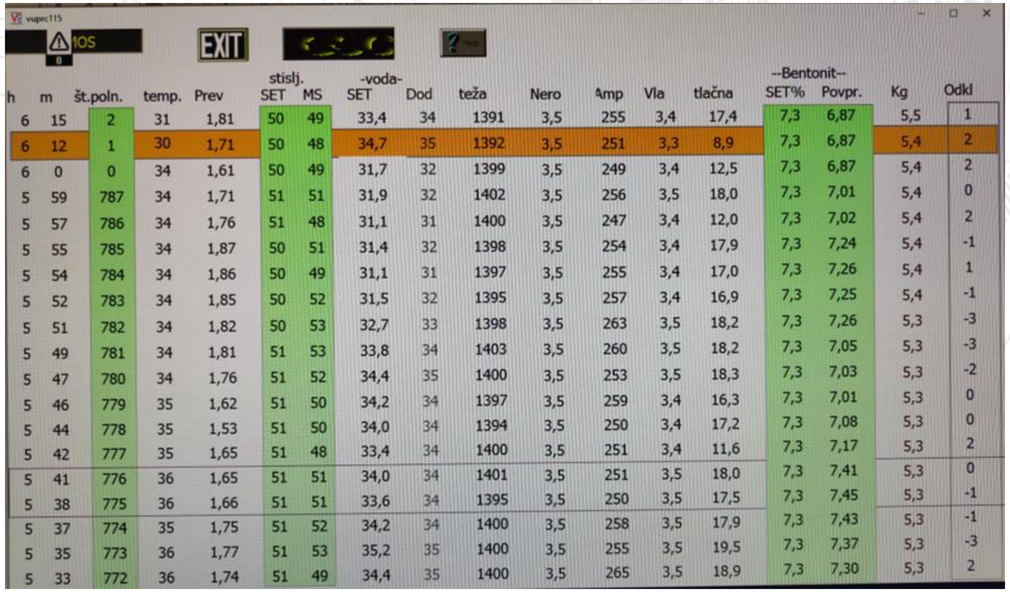
Device for Green sand control – Belloi & Romagnoli

The results of each batch of bentonite sand mix produced consequently allow a more accurate analysis.



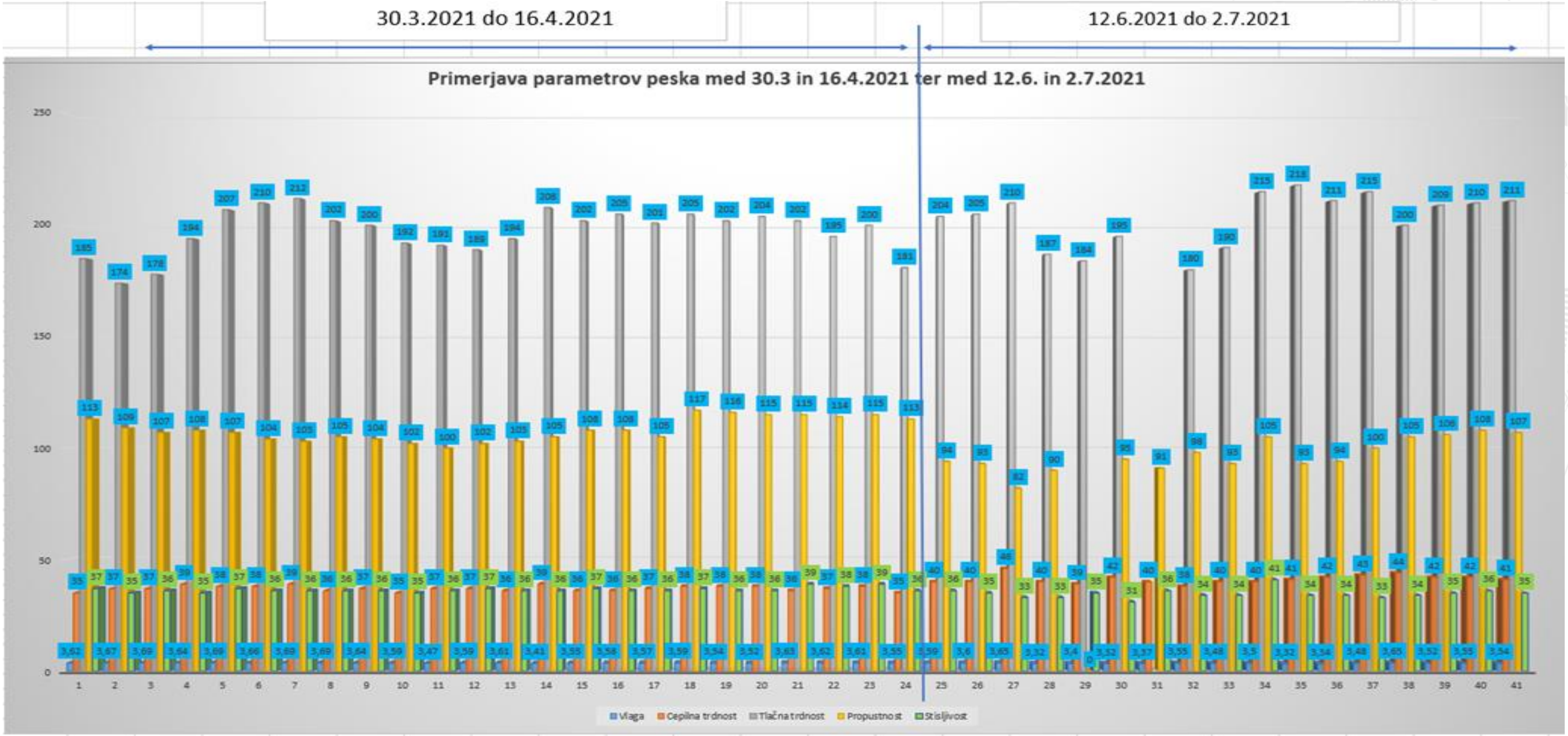




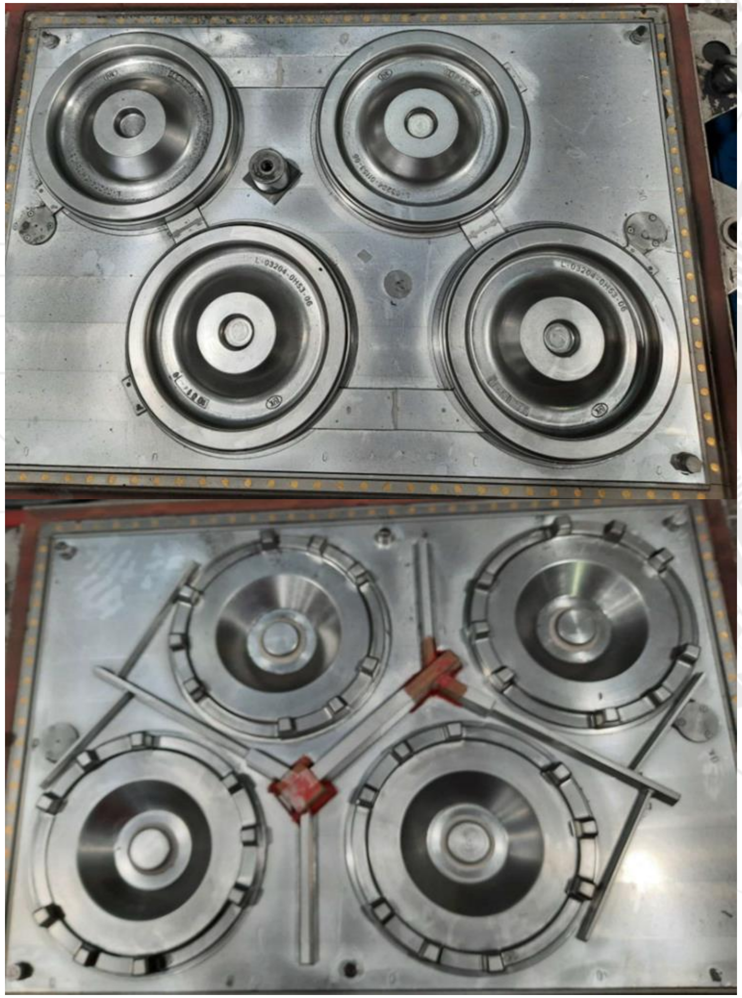
h	m	št.poln.	temp.	Prev	stislj. SET	stislj. MS	-voda- SET	-voda- Dod	teža	Nero	Amp	Vla	tlačna	--Bentonit-- SET%	--Bentonit-- Povpr.	Kg	Odkl
6	15	2	31	1,81	50	49	33,4	34	1391	3,5	255	3,4	17,4	7,3	6,87	5,5	1
6	12	1	30	1,71	50	48	34,7	35	1392	3,5	251	3,3	8,9	7,3	6,87	5,4	2
6	0	0	34	1,61	50	49	31,7	32	1399	3,5	249	3,4	12,5	7,3	6,87	5,4	2
5	59	787	34	1,71	51	51	31,9	32	1402	3,5	256	3,5	18,0	7,3	7,01	5,4	0
5	57	786	34	1,76	51	48	31,1	31	1400	3,5	247	3,4	12,0	7,3	7,02	5,4	2
5	55	785	34	1,87	50	51	31,4	32	1398	3,5	254	3,4	17,9	7,3	7,24	5,4	-1
5	54	784	34	1,86	50	49	31,1	31	1397	3,5	255	3,4	17,0	7,3	7,26	5,4	1
5	52	783	34	1,85	50	52	31,5	32	1395	3,5	257	3,4	16,9	7,3	7,25	5,4	-1
5	51	782	34	1,82	50	53	32,7	33	1398	3,5	263	3,5	18,2	7,3	7,26	5,3	-3
5	49	781	34	1,81	51	53	33,8	34	1403	3,5	260	3,5	18,2	7,3	7,05	5,3	-3
5	47	780	34	1,76	51	52	34,4	35	1400	3,5	253	3,5	18,3	7,3	7,03	5,3	-2
5	46	779	35	1,62	51	50	34,2	34	1397	3,5	259	3,4	16,3	7,3	7,01	5,3	0
5	44	778	35	1,53	51	50	34,0	34	1394	3,5	250	3,4	17,2	7,3	7,08	5,3	0
5	42	777	35	1,65	51	48	33,4	34	1400	3,5	251	3,4	11,6	7,3	7,17	5,3	2
5	41	776	36	1,65	51	51	34,0	34	1401	3,5	251	3,5	18,0	7,3	7,41	5,3	0
5	38	775	36	1,66	51	51	33,6	34	1395	3,5	250	3,5	17,5	7,3	7,45	5,3	-1
5	37	774	35	1,75	51	52	34,2	34	1400	3,5	258	3,5	17,9	7,3	7,43	5,3	-1
5	35	773	36	1,77	51	53	35,2	35	1400	3,5	255	3,5	19,5	7,3	7,37	5,3	-3
5	33	772	36	1,74	51	49	34,4	35	1400	3,5	265	3,5	18,9	7,3	7,30	5,3	2

Device for Green sand control – Belloi & Romagnoli

Comparison of results from the sand laboratory for two time periods:



Replaced (reversed) model plates with adapted casting system



Increasing the radii on the casting engraving

- Before increasing radii

- After increasing radii

Internal and external scrap after increasing the radii on the casting engravings

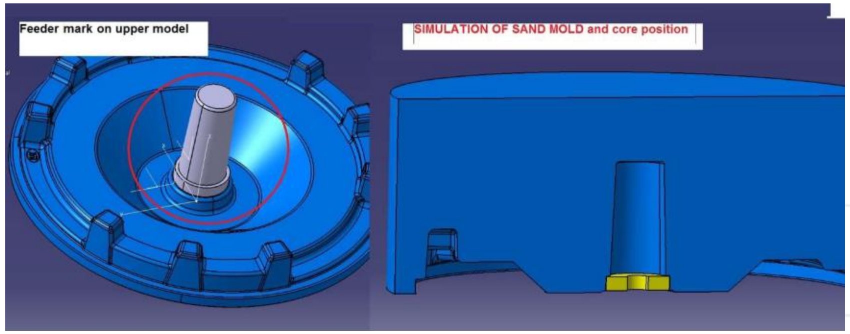
- Results of the internal scrap 72 out of 260 pieces or 27.7%:

- After machining, out of 188 pieces, 28 castings were bad or 14.9% of which 14 pieces were shrinkage porosity and 14 pieces were gas blister.

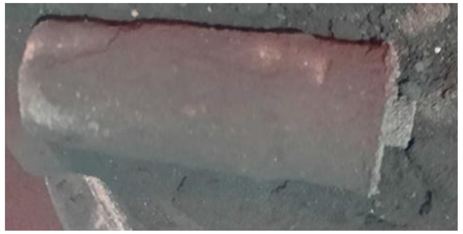
- The total scrap were therefore 100 pieces, or 38.46%.

Feeder with separation plate

- Simulation of the feeders design



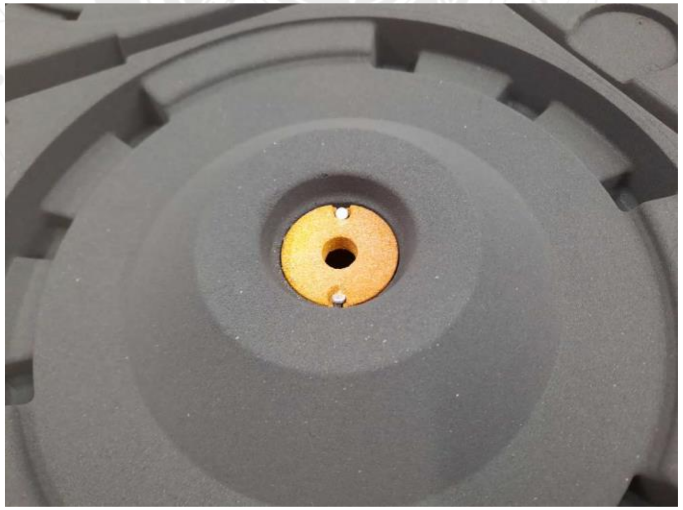
Feeder on the casting



- Two variants of separator plates

- ✓ Fixing with one nail

- ✓ Fixing with two nails



Exothermic feeders

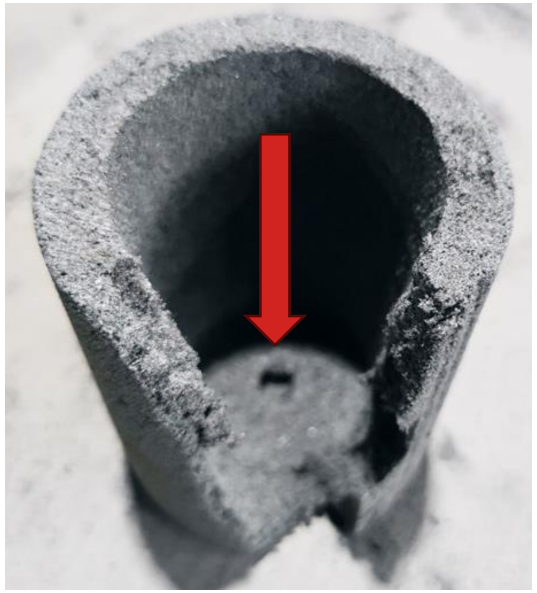
- Problems with the metal neck of the exothermic feeder - falling out

Selected type of exothermic feeders- up to 2 % scrap after machining

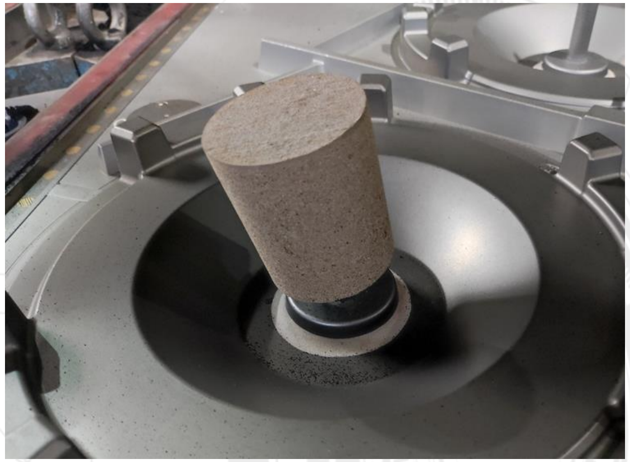
Exothermic feeders

- Eccentrically glued metal part

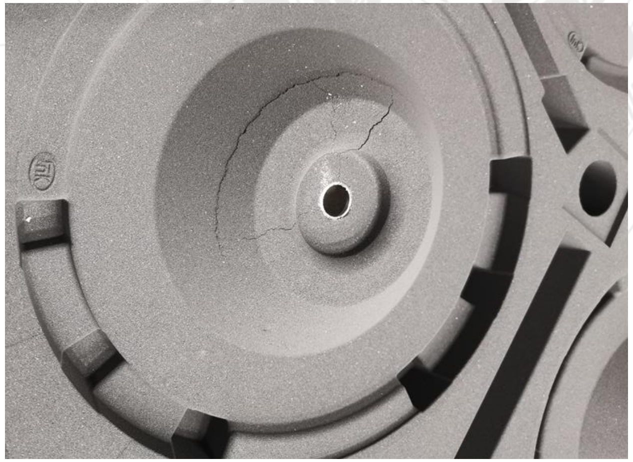
- Guide hole for metal carrier



- Correctly and incorrectly positioned exothermic feeder



- Incorrect positioning of the exothermic feeder on the metal carrier results in a broken mould and scrap castings.



Conclusions

- During the casting validation process, the simulated 15% shrinkage porosity inside the casting was not disturbing to the customer.
- After a certain period of time, we were warned that the shrinkage porosity had to be eliminated.
- Optimizing the technological process was not enough to eliminate shrinkage porosity.
- The analyses carried out have shown that the self-feeding capacity of grey cast iron and compliance with the technological regulations are not sufficient to eliminate shrinkage porosity.
- The purchase of a Green sand control - Belloi & Romagnoli to monitor the parameters of each sand mix produced has contributed to the repeatability and consistency of the sand mix.
- We have also invested in a device for melt modification (FOSECO MSI 900) to ensure the repeatability of melt modification.
- Improving the quality of the raw materials and the use of pig iron are also no guarantee of the good quality of the castings (without shrinkage porosity).
- Using ATAS MetStar system from supplier NovaCast Systems (Mr. Andrej Kump), the results of the TA analyses were analyzed and direct correlations were found between the individual impact parameters (R, GRF1, GRF2) and the external scrap and shrinkage porosity.
- It was necessary to feed the casting with exothermic feeders FOSECO (with the assistance of Mr. Branko Čeh-FEAL d.o.o).
- Despite the increase in costs due to exothermic feeders, we were able to ensure the required quality of castings and reduce the cost of defects (lower then 2.5% after machining) and the occasional cost of extraordinary transports, freeing up capacity on the Heinrich Wagnar Sinto D-5928 moulding line.

Thank you for your attention!

Let‘s make things happen,
stay motivated . . . running ahead!