Pot Blasting Abnormality Control at Balco

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Abstract

Aluminum industry uses high temperature electrolysis to extract pure liquid aluminum from alumina. An Aluminium production line consists of several electrolytic cells connected in series. Any sudden pot tap-out, may lead to amperage hinderance, and thereby disturbance to the physical condition and process parameter control for all the pots in the circuit. By managing the operational practice discipline and focused process parameter control, BALCO was achieving benchmarking low power consumption consistently. In the last few months, Balco was facing an issue of sudden pot tap-out or strong red shells due to pot blasting (explosion). In this paper, we briefly discuss, how we proceeded to understand the probable root causes for such sudden blasting, implement control actions and reduce occurrence of such abnormality.

Keywords: Pot blasting, Power consumption, Pot tap-out, Control actions, Low power consumption.

1. Introduction

Aluminium manufacturing is a high intense power consuming sector (almost 14 kWh/kg Al). The process involves reduction reaction of alumina to aluminium in an electrolytic cell. Cathode of the cell lies on the shell bottom over which electrolyte and anode assembly are placed. Hence, it is obvious that the life of the cell is highly depended on the cathode stability. When starting a pot, cathode is expected to remain intact until the age of 1800-2000 days. If the cell life is lower, the whole cell is cut out and restarted, which is quite expensive. Additionally, in a modern aluminium smelter, there are more than 300 pots that are connected in series to one another in a single bus-bar circuit. Abnormalities in a pot include open circuit or pot tap-out, which have potential to damage the bus bar circuit, thereby involuntarily stop several pots together.

In any aluminium smelter pot tap-out is a known phenomenon in which the hot electrolyte or metal inside the pot pours out through the protective potshell. At BALCO, in last few years, we were observing a crucial phenomenon of sudden blasting, quite violent local explosion, in a particular position in many pots at different instances, mostly followed by a severe red hot side walls of the potshell, and often even proceeding to a pot tap-out. This report summarizes the direction and findings of investigation into the root causes of the pot blasting and green patching. The pot blasting predominantly occurs on top of pot shell outer surface with visible or sometime less visible cracks having dispersed bluish green patches. Also, few short-term mitigating actions to help prevent blasting will be described, and the potential causes of the underlying conditions that may cause the blasting will be proposed.

2. Impact of Pot Blast

Table 1 shows the frequency of pot blasts. The pot blasting and associated pot shell hot spots were first observed in August 2017 and was happening at irregular intervals in many pots.

Table 1. Pot blasts since 2017.

From January 2017	Number of pots	Number of locations	Remarks
Total blast location	50	18	Side shell
Total blast occurred in pots	50	50	Side shell
Controlled blast but still stopped	38	26	Medium impact
Blasted and leaked	12	12	High impact tap-out

With reference to Table 1, the frequency of pot tap-out is 24 % (12/50 pots), which is very high. When pot blasting happens unexpectedly, there is a generation of intense energy in the cell, which initially damages to pot hood, rim and deck plate (Figure 1). The potshell starts getting hot spots which may result in pot tap-out (Figure 7). There is also risk of a complete potline failure through an open circuit, earthing faults or busbar damage.

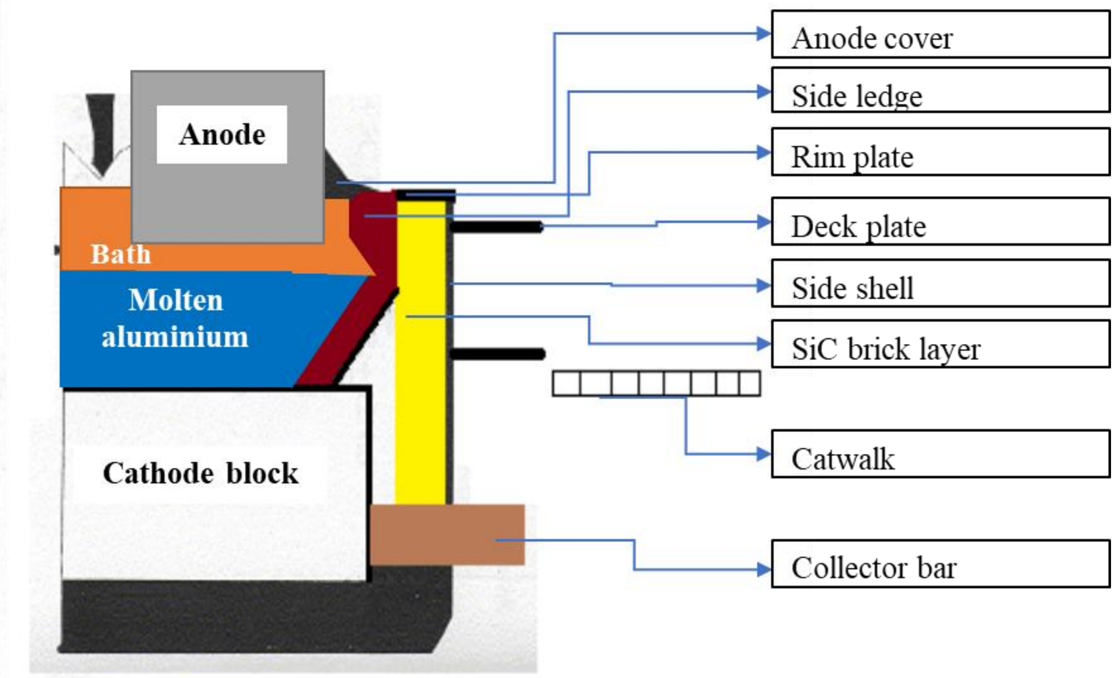

Figure 1. Partial cross-sectional view of pot and nomenclature (area related to blasting).

3. Analysis Approach

The analysis approach is shown in Figure 2. This analysis followed a review of a few pertinent papers [1-2], but no such abnormality was found in the literature.

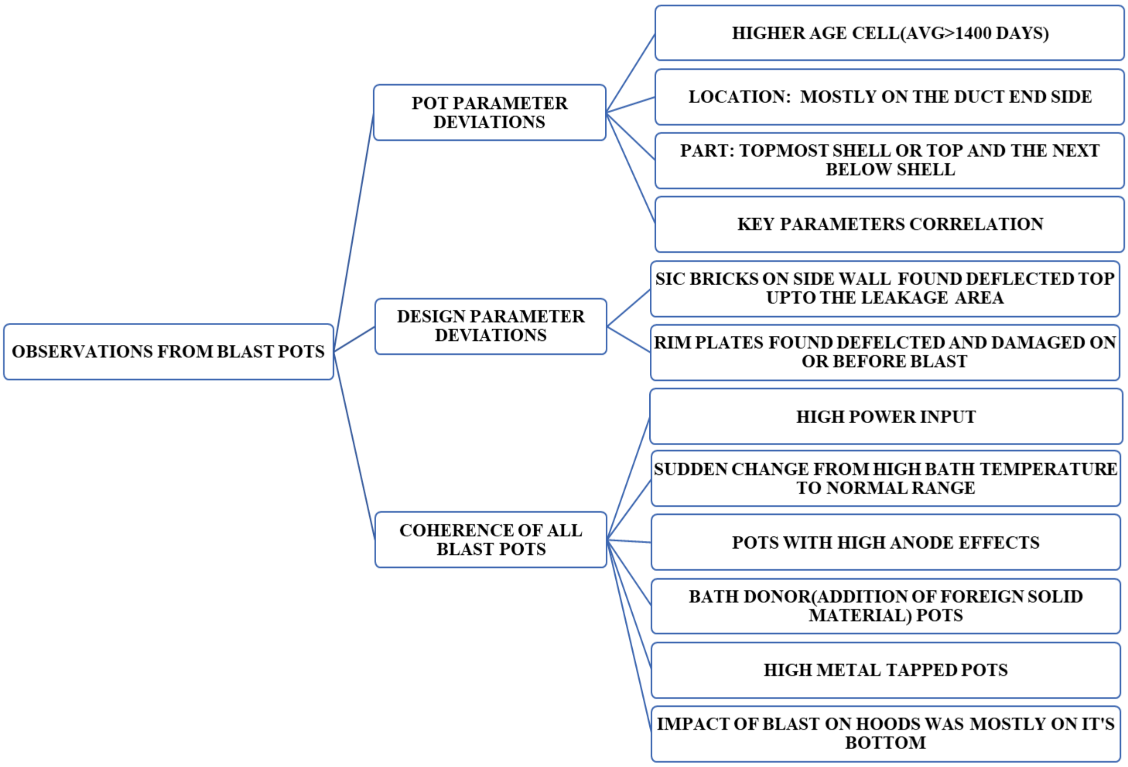

Figure 2. Observations for a blast pot.

4. Key Inferences

The direct cause of the blast has not been determined. Here are the results of the investigations and some hypotheses:

1) Initially, a hypothesis was launched that the blasting is the result of a strong electrical arc in the area. After due consideration and analysis, this was not proven and is deemed to be unlikely because of high bath resistance from the anode to the shell and no signs of large currents or arcing was found on the outside of the shell or on the collector bars. However, some electrical current could be passing in that path shown in Figure 3.
2) If the electrical current is passing through the blast area, it is driven by the voltage drop from the anode to the potshell, rather than due to any shorting between pot to earth. The latter was confirmed by audits done on all survived pots and their insulation resistances to earth were measured and were found high.
3) Pot hood insulation may also not be ensured across all hoods. There is a fair possibility of insulation failure causing electrical shorting from the anode to the rim plate. However, in few sections all hoods were replaced with new insulated hoods, but the blast occurred in some pots of those sections, too. This eliminates the possibility of shorting from hoods to rim plate
4) An alternative possibility of a thermite reaction caused by the presence of metallic aluminium in the anode cover and side crust was ruled out as the anode cover material samplings were found free from metallic aluminium.
5) In almost all blast locations, hoods that were found damaged are mainly in their lower part, from the blasting occurring within the area between anode side and the pot sidewall.
6) In almost all blast locations, the rim plate was found deflected upwards at the time of blasting or before (Figure 3).
7) In most of the blasted pots, there were 50-60 mm of silicon carbide sidewall left at the bath metal interface and 70-80 mm left at the top of the silicon carbide block. Therefore,

the path for liquid bath to get to the steel shell and cause hotspots and tap-outs is likely over the top of the silicon carbide block.

8) A brief parameter study of last 22 blasted pots was carried out with SCCR Aluminium Consulting Group. Table 2 describes that the ranges of parameters of blasted pots are within normal pot standard deviation. This explains that the blasting is not based on historic parameters but instantaneous abnormality.

Table 2. Parameters of 22 blasted pots.

POT	AGE	CATHODE	SetV	Avg Vol	Delta avg v mV	BL	LAST MEASURED BT	Noise	AEF IN LAST 3 DAYS	AED IN LAST 3 DAYS	Alumina Feed	Avg Alf3 IN LAST 3 DAYS	FE	fe diff IN LAST 3 DAYS	Si	Si IN LAST 3 DAYS	Xs Alf3	UF count
Pot A	1256	SGL 50%-FV	4.094	4.156	-3	17	965	16	0	0	5087	55.0	0.107	-1.3	0.1	-1.0	8.99	-167
Pot B	1738	NEW C. SAVOIE	4.08	4.158	30	17	977	40	0	0	4820	45.7	0.079	-8.7	0.061	-3.5	11.28	21
Pot C	1881	NEW C. SAVOIE	4.15	4.148	24	12	946	17	5	19	5645	9.3	0.076	-10.0	0.083	0.0	7.5	-136
Pot D	1479	SGL 50%-F	4.11	4.159	13	16	962	13	0	0	5320	46.0	0.103	4.0	0.119	-19.0	11.62	-25
Pot E	2083	SGL 50%-F	4.097	4.182	59	19	965	26	0	0	4986	66.0	0.081	2.7	0.103	21.5	6.65	16
Pot F	1559	SGL 100%	4.057	4.046	-16	16	970	8	0	0	4965	67.7	0.081	-2.3	0.068	-4.0	12.01	141
Pot G	1493	SGL 50%-F	4.12	4.124	-2	17	965	21	2	7	5197	59.3	0.093	9.7	0.068	7.0	12.76	286
Pot H	1172	SGL 50%-F	4.12	4.136	-24	13	970	12	0	0	4914	62.0	0.084	-5.3	0.079	-1.5	8.61	133
Pot I	1737	NEW C. SAVOIE	4.11	4.105	-28	17	981	9	0	0	4610	157.7	0.069	-3.3	0.071	-1.0	8.86	40
Pot J	889	SGL 100%	4.06	4.086	3	17	964	8	0	0	4816	69.3	0.065	-5.0	0.067	-2.0	9.8	131
Pot K	1316	SGL 50%-F	4.12	4.115	-22	17	965	9	0	0	4990	41.3	0.081	2.3	0.077	0.0	14.43	43
Pot L	1505	SGL 100%	4.057	4.085	27	17	962	14	0	0	4639	58.7	0.081	0.0	0.085	11.0	11.07	20
Pot M	1467	SGL 50%-F	4.15	4.144	17	18	957	20	3	7	5125	37.3	0.081	1.3	0.063	0.5	10.95	50
Pot N	1838	NEW C. SAVOIE	4.11	4.118	11	12	965	14	1	1	4794	53.3	0.076	-7.3	0.107	-7.5	15.96	
Pot O	1395	SGL 100%	4.09	4.09	-15	15	967	8	0	0	4514	43.3	0.079	-2.7	0.058	-1.5	11.17	165
Pot P	1742	SGL 50%-F	4.11	4.144	14	15	948	20	1	2	5176	46.0	0.081	2.7	0.061	1.5	9.59	-68
Pot Q	1455	SGL 50%-FV	4.11	4.12	-2	15	964	7	0	0	4820	82.7	0.082	-0.7	0.064	1.5	9.79	29
Pot R	1256	NEW C. SAVOIE	4.15	4.108	-20	0	961	12	4	13	4133	58.7	0.075	-2.7	0.059	0.0	12.84	
Pot S	1416	SGL 50%-F	4.06	4.044	-5	18	965	8	0	0	5029	104.7	0.071	-3.0	0.065	-1.0	8.37	-41
Pot T	1536	SGL 50%-F	4.13	4.223	65	15	971	21	0	0	4368	4.0	0.083	1.3	0.076	3.5	15.6	-28
Pot U	1174	SGL 50%-F	4.154	4.205	94	0	939	20	1	1	4762	0.0	0.085	4.7	0.066	3.5	13.22	-117
Pot V	1456	SGL 50%-F	4.09	4.11	-16	13	969	12	0	0	5013	88.3	0.059	-6.7	0.05	0.0	12.78	259

	SetV	Avg Vol	Delta avg v mV	BL	LAST MEASURED BT	Noise	AEF IN LAST 3 DAYS	AED IN LAST 3 DAYS	Alumina Feed	Avg Alf3 IN LAST 3 DAYS	FE	fe diff IN LAST 3 DAYS	Si	Si IN LAST 3 DAYS	Xs Alf3	UF count
Min in blast pots	4.057	4.044	-28.4	0.0	939	7	0.0	0.0	4133	0	0.06	-10	0.05	-19.0	6.65	-167
Max in blast pots	4.154	4.223	93.8	19.0	981	40	5.0	19.0	5645	158	0.11	10	0.12	21.5	15.96	286
Blast pots parameter stdev	0.031	0.045	31.3	5.0	9	8	1.4	5.0	328	34	0.011	4.79	0.018	7.29	2.50	121.0
Normal pots std dev	0.026	0.044		1.7	10	4			268	24	0.028		0.024		2.27	92.93

Conclusions from these observations:

The upwards deflection of the rim plate happens slowly (Figure 4) from the inner edge creating a gap. This damages the grout between the top of the silicon carbide bricks and the bottom surface of the rim plate. When the liquid level is high, this exposes the potshell to impingement of liquid bath directly through the gap (Figure 3).

The penetration of hot liquid bath above the silicon carbide block, forming a liquid pathway directly to the steel shell is what causes blasting from inside. If bath penetrates downward between the steel shell and the silicon carbide sidewall blocks, then hot spots would have occurred at the side bottom shell, but instead, hot spots occur at the top of the shell and at rim plate area (Figures

5.A, 5.B). This type of hot spotting can cause the failure of the steel sidewall and ultimately cause the pot to tap out, as has been observed on many occasions (Figure 7). In several cases, Blasting is not likely found causing hotspots when sustained for less than 5-20 seconds.

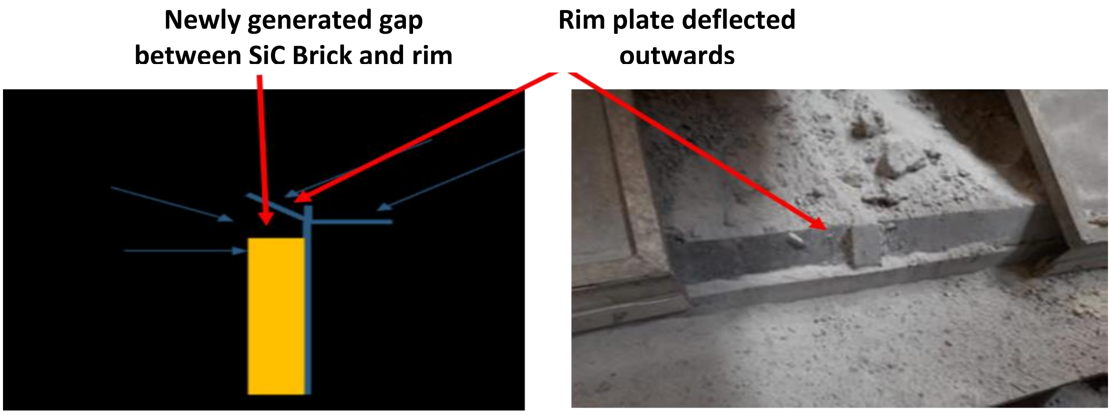

Figure 3. Deflection occurring in rim plate.

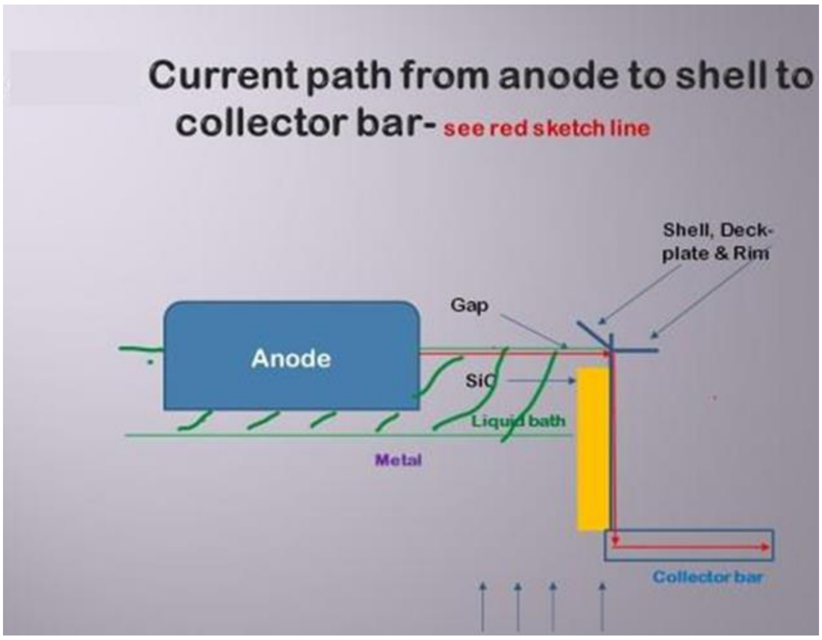

Figure 4. Path of bath penetration from top of SiC brick via gap between shell and SiC brick. The electric current can pass directly from the anode to the collector bars.

Figure 5 A. Picture of hot blasted area.

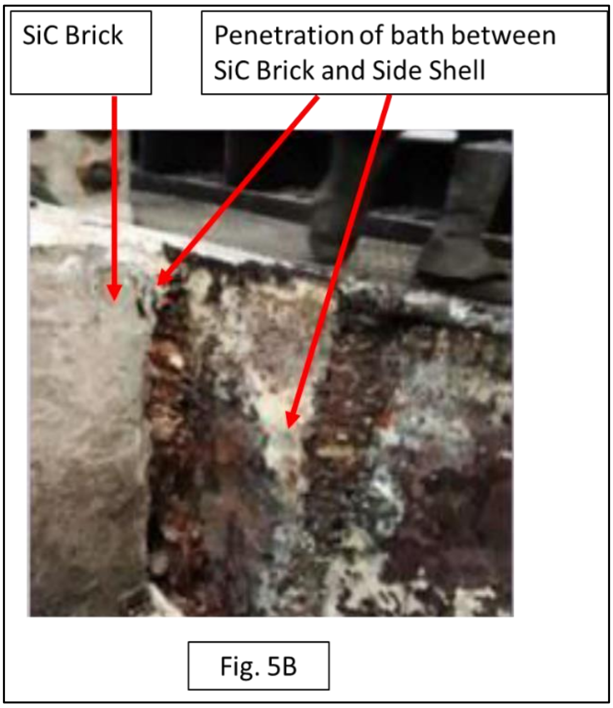

Figure 5 B. Picture of the shell area of blasted pot depicting traces of bath penetration between the shell and SiC from top.

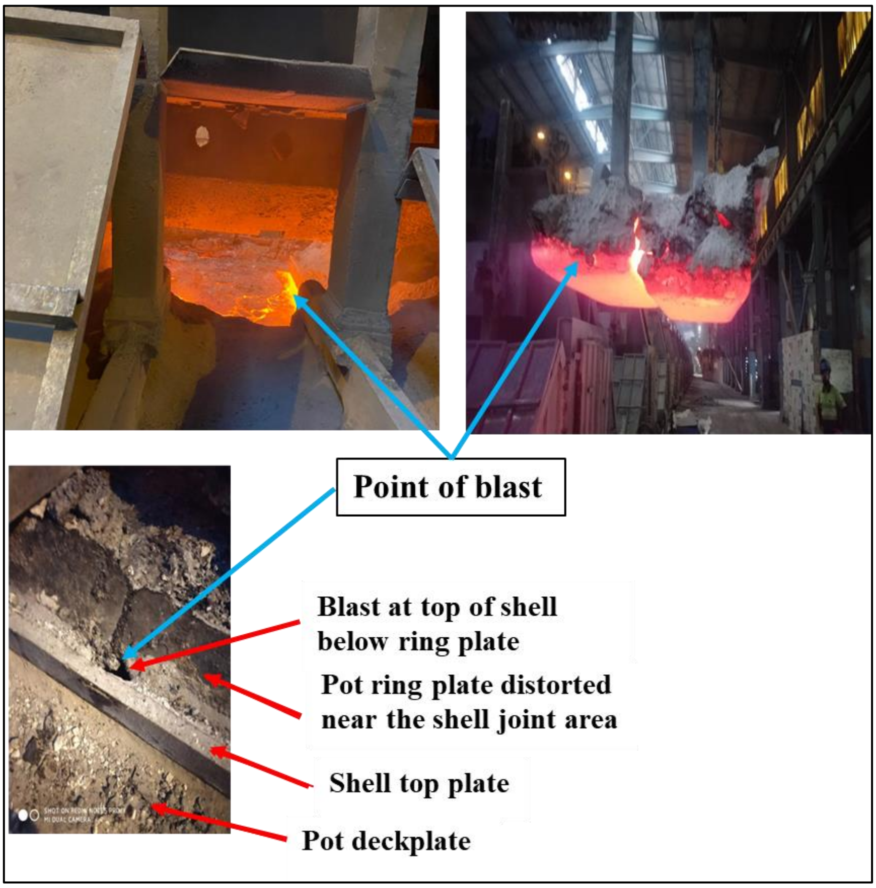

Figure 6. View of blast area - Inner shell (top left), Anode (top right), Rim plate (bottom).

Figure 7. Pot leakage from side shell through hot spot.

In summary, the essential alignment of factors underlying the possibility for blasting, shell hot spots and associated tap-outs are:

- The lack of protective freeze at the top of the silicon carbide block
- When the liquid bath level is high enough to flow over the top of the sidewall and if uncorrected, the liquid bath ultimately makes direct contact with the pot shell.

5. Contributing Process and Operational Factors

As pots age, cathode heave may occur. Pot voltage and metal pad targets are raised to counteract increased pot instability and temperature. During early days of potlife, target metal level of pots is around 25 cm. In older pots the target metal height increases to 30 cm or even more based on individual cell condition. Bath height target is kept 17-18 cm. This makes total liquid cavity between 47-52 cm. In potline, the cavity depth to the top of the silicon carbide block is 55 cm. With any minor variations in metal or bath levels, there is significant potential to have total liquid in cavity above the silicon carbide sidewall blocks.

Blasting peaked at BALCO in August 2019 when the number of pots with high liquid levels also peaked (Figure 8), despite the number of pots older than 1200 days being relatively low. This data explains high correlation between high liquid levels in pot and blasting rather than just bath level (Figure 9). In due course we realized that the cause for blasting were high liquid levels in the pot cavity rather than just the high bath level.

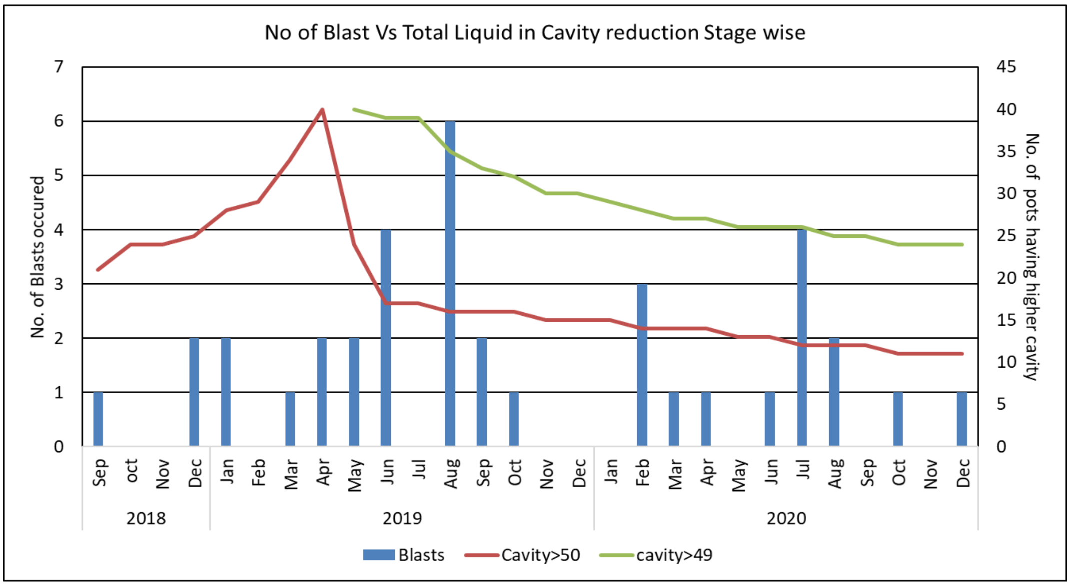

Figure 8. Trends of the number of blasts occurred and stage-wise reduction of total liquid level in pot cavity.

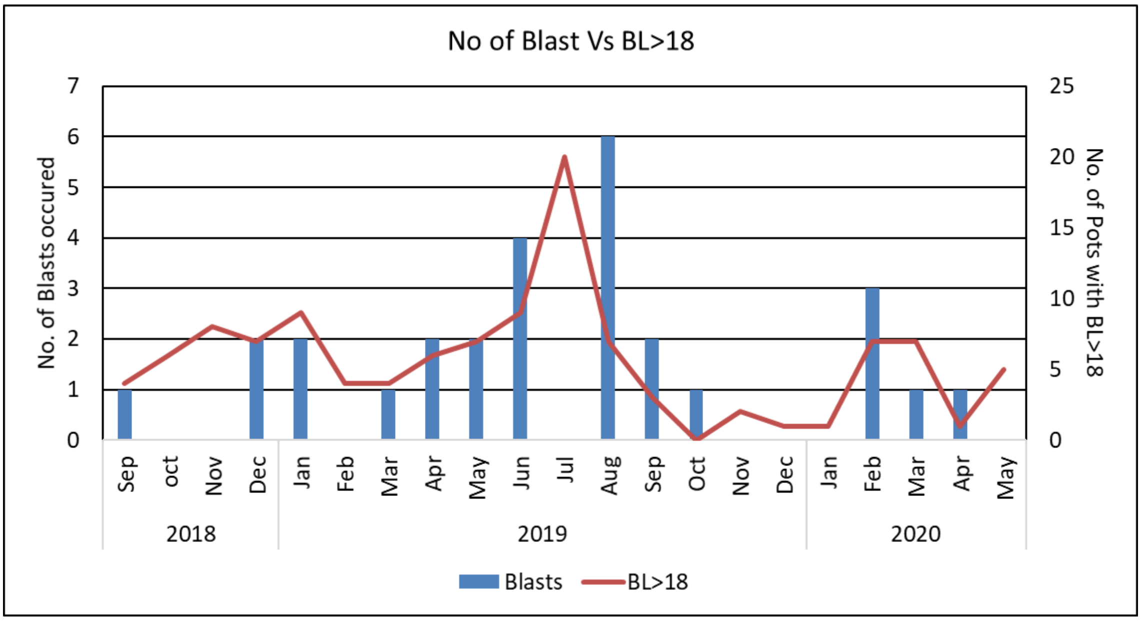

Figure 9. Trends of number of blasts and pots with high bath levels (BL) in cm.

6. Actions and Learnings

Immediate actions to prevent the arcing / blasting events from occurring:

1. Identify pots with predisposing conditions, for immediate and continuous monitoring of indicators
    - Green patches which were expected to be a major indicator of the risk of blasting were found not having much correlation. Still, these patches may indicate deterioration of the SiC structure and the generation of harmful reaction products.
    - Pots with the predisposing conditions above should not be used as donor pots and subjected to operate with higher levels of liquid.
2. Pot shell temperatures at the level of the deckplate area should be routinely monitored, preferably using a thermal imaging camera. This will give the capability to pick up developing issues at an early stage before temperature increase is detectable by the human eye.
3. Revise the AlF_3 addition practices. It was noted that several pots were high in % excess AlF_3 and AlF_3 was still being added when they blasted (Figure 10). AlF_3 addition table should be revised periodically and tracked on daily basis. Also, raw material specifications should be optimized to reduce incorrect AlF_3 feeding.

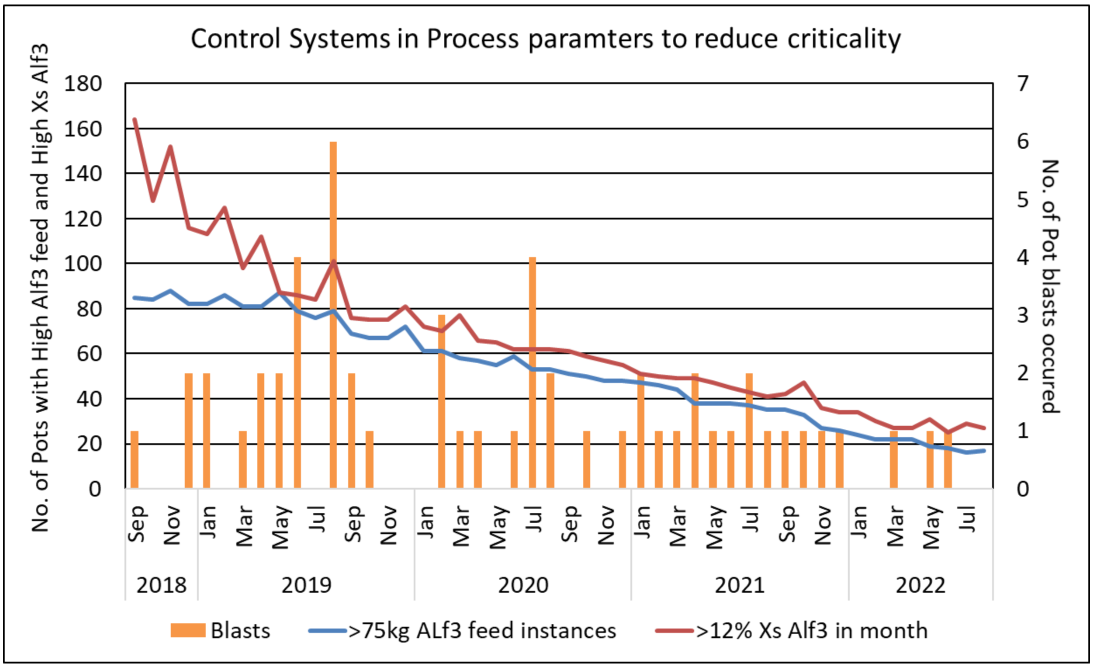

Figure 10. Trends of AlF_3 feed and excess AlF_3 parameters deviation control on course of action.

4. Preliminary action was monitoring frequently the areas where predictive abnormality such as green patch, high side shell temperature had been observed in recent past. Cleaning of rim plate area was included in pot-redressing procedure and regular awareness was provided to the potroom team about the importance of maintaining rim plate in shape for pot blast control. Cleanliness of rim plate in anode redressing audit was assigned to responsible technical in-charge daily audit checklist and tracked.
5. The next action was controlled step-wise reduction of the total liquid level (Figure 11) so that it was maintained below the design pot cavity depth. Initially, the reduction was by 5 cm making total liquid level target < 50 cm (by November 2018) on daily liquid level measurement. Later by June 2019 the target was further revised to maintain < 49 cm of total liquid height, and this helped considerably the reduction of blasting frequency. The liquid level was finalized to a target of < 48 cm from July 2020. This helped to prevent the penetration of liquid bath into the gap between the shell and the SiC block, if it formed. This journey of reducing the total liquid height by 7 cm helped controlling pot blasts. The observation from 2017 and its step-by-step learning and control helped BALCO in reducing the abnormality by 2021, during which the number of old age pots increased (Figure 12).

Table 3. Number of blasted pots at various pot age ranges, Financial Year (FY)-wise.

FY\Age Range->	850-1349	1350-1849	1850-2350		Grand Total
2018		1			1
2019	1	2	3		6
2020	6	11	4		21
2021	2	9	3		14
2022	1	7	4		12
2023	0	0	2		2

Data on the above table (Table 3) show that the number of blasting significantly reduced in pots having age < 1850 days, over a period of last 3-4 years. However, in older age pots the number instances were still prevailing due to deformed rim plate gaps that could not be repaired once it gets out of shape. Also, the Total liquid level reduction and control was comparatively difficult and delayed in older pots.

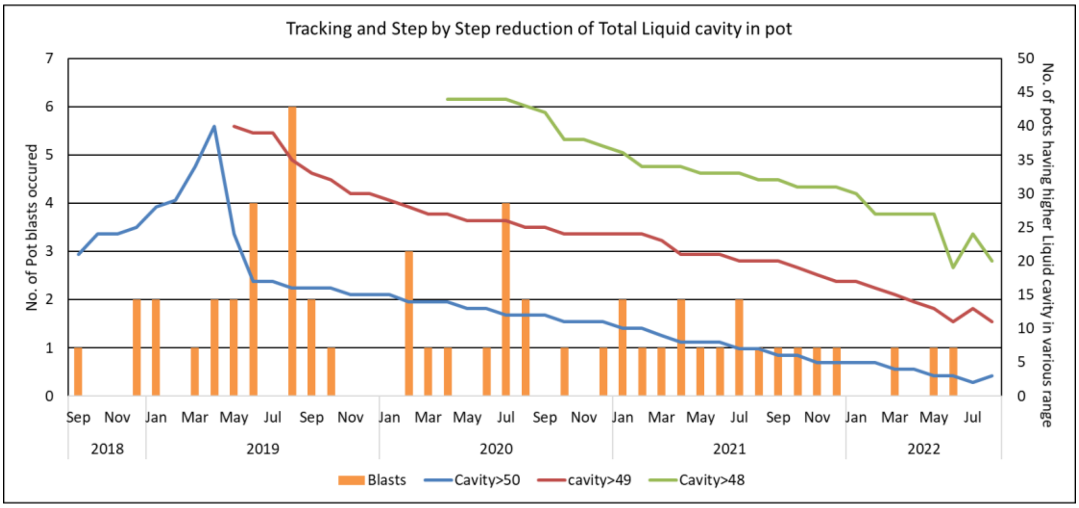

Figure 11. Tracker for total liquid cavity in various stages to controlled Pot Blast instances.

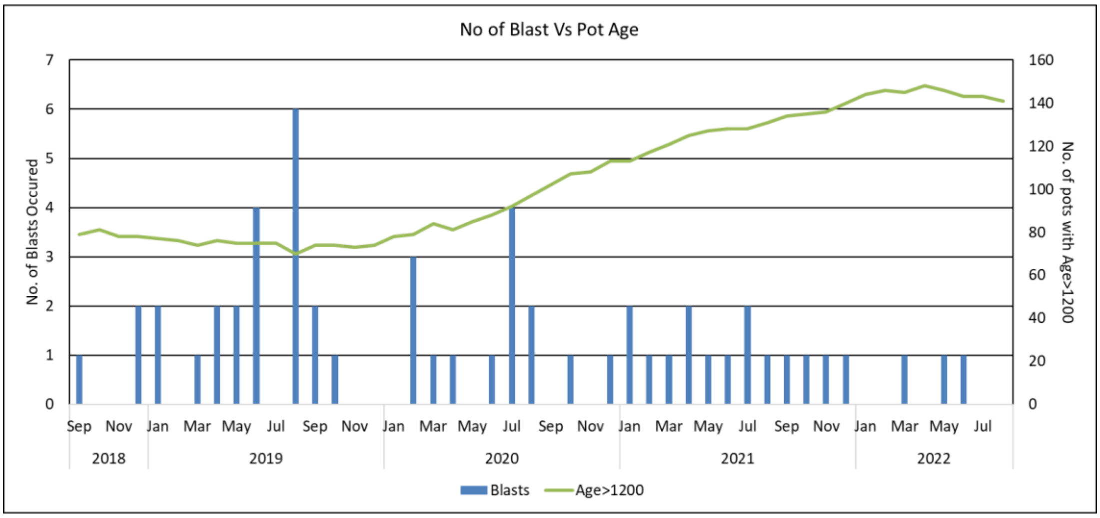

Figure 12. Trend of Pot Blast with Number of pots with age >1200.

7. Conclusions

Major root cause for pot blasting is rim plate widening due to process parameter deviations and excessive anode cover that slide up-to pot rim plate. This once again strongly emphasizes that the basic potline parameters must be always under control.

Total liquid height reaching to the top of cavity depth allowed the bath to penetrate behind the detached SiC bricks. This was also the cause of red-hot shells and eventual pot tap-out. Control of the total liquid height to a 7 cm lower value contributed to a decrease of the number of blasts.

Acknowledgement

We are grateful to SCCR Aluminium Consulting Group for valuable advice and data analysis.

8. References

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