Performance Optimization of Cement Free Alumina Magnesia Dry Gunning for Steel Ladle

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1 Introduction

The more rebound loss and poor lining service life of dry gunning solution with traditional materials are the main factors that limited its application in steel ladle repairing.

Since the cement free alumina magnesia dry gunning mixes with excellent lab and jobsite performance are reported by previous articles, it provides a new route to overcome the above drawbacks.

This paper aims to further improve the cement free alumina magnesia dry gunning mixes by comparing 3 mixes containing different MgO with 2 low cement castable.

Repair model	Veneer Casting	Dry gunning	Shotcreting
Construction process	Residual lining surface treatment→ Mold installation→ Casting→ Curing→ Demolding→ Dry out	Residual lining surface treatment→ Gunning/shotcreting→ Dry out	
Product	Al_2O_3-MgO Castable	Al_2O_3-MgO dry gunning	Al_2O_3-MgO castable+ hardening agent
Main equipment	Mixer	Dry gunning machine	Mixer+ shotcreting machine
space for installation	more	**minimal**	moderate
Time-consuming	more	**minimal**	moderate
Equipment complexity	moderate	**simple and easy**	more complexity
rebound loss	less	**more**	moderate
Lining service life	better	**poor**	moderate

2 Experiment Process –formulation design

In cement free dry gunning mix (G1, G2, G3):

- MgO varies in different recipes with same reactive alumina MC-G + reactive alumina B content

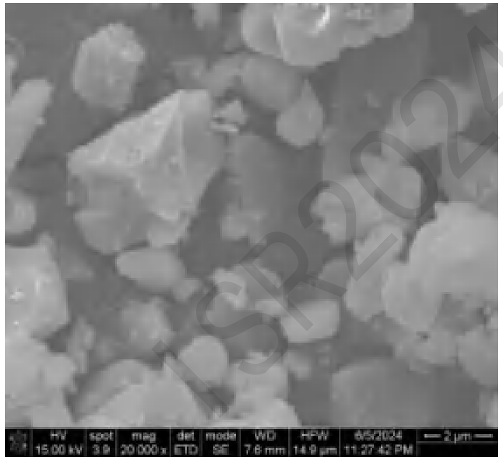
In low cement castable(CS, CM):

- Preformed and *in-situ* spinel with same calcined alumina A + reactive alumina B content

Recipe No.	G1	G2	G3	CS	CM
sintered alumina 6-0 mm	75	70	67.5	59	77
78% sintered spinel 1-0 mm				23	
97% fused magnesia 1-0 mm	7.5	12.5	15		5
calcium aluminate cement				5	5
calcined alumina A				8	8
reactive alumina B	10	10	10	5	5
reactive alumina MC-G	7.5	7.5	7.5		

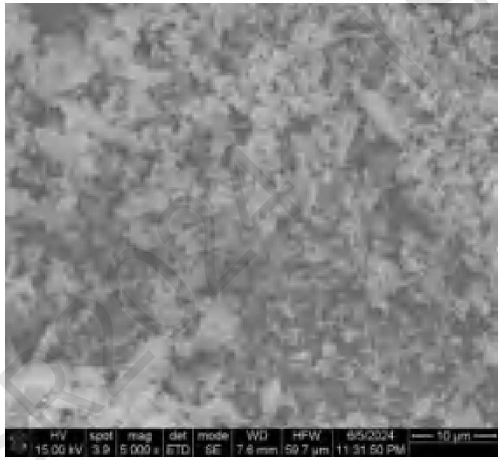
a typical calcined alumina with smoother and bigger crystal

calcined alumina A 5 000X

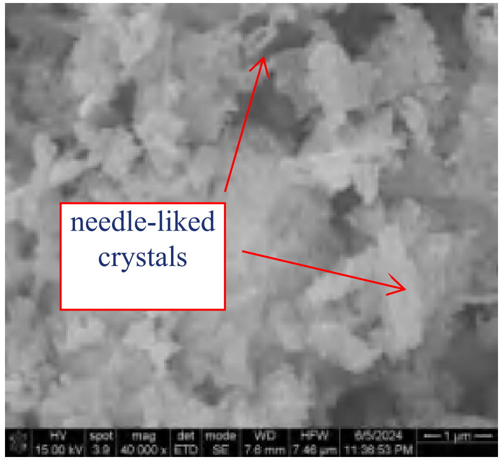


calcined alumina A 20 000X

Many plate and needle-like crystals with size less than 1 μm



reactive alumina MC-G 5 000X



reactive alumina MC-G 20 000X

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3 Result and Discussion- sample preparation (fast cast method)

For cement free dry gunning mix samples:

- dry mixed for 5 minutes→ wet mixed with liquid for another 1 minute at 120 RPM→ rammed and for another 1 minute→ standard curing.

For low cement castable samples:

- dry mixing for 5 minutes→ wet mixed with liquid for another 5 minutes at 30 rpm speed→ vibrating for 1.5 minutes→ standard curing process.

Dry gunning mix samples are rammed and demolded

3 Result and Discussion- physical properties

- With the increasing of MgO in the dry gunning mixes, the sample's PLC after 1600℃ changed from slight contraction to significant expansion, which is accompanied with an increasing of AP and decreasing of mechanical strength.

- The high expansion of in samples after 1600℃ is due to the spinel forming effect.

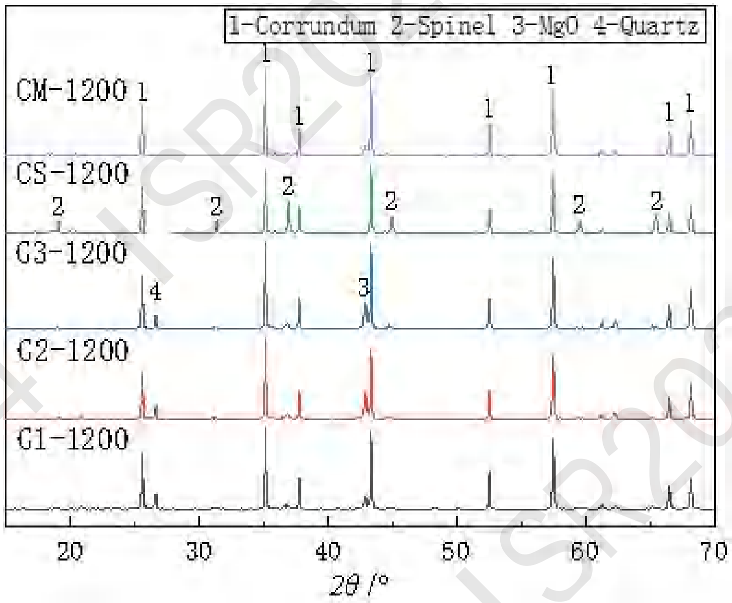
Recipe No.	G1	G2	G3	CS	CM
fired at 1200℃					
CMOR MPa	15	12	11	13	17
CCS MPa	90	80	80	79	96
AP %	22	22	22	22	18
BD g/cm^3	2.88	2.91	2.88	2.96	3.09
PLC %	-0.09	0.01	-0.10	0.06	0.13
fired at 1600℃					
CMOR MPa	22	19	18	33	25
CCS MPa	77	64	62	142	114
AP %	19	21	22	19	21
BD g/cm^3	2.91	2.81	2.77	2.99	2.91
PLC %	-0.16	0.92	1.31	-0.13	2.17

3 Result and Discussion- XRD Analysis

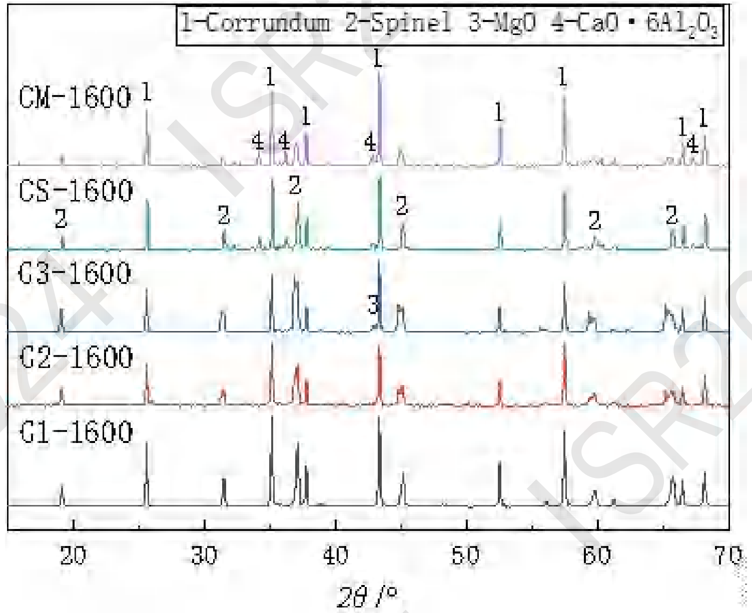
- The spinel peak of dry gunning mixes is stronger than that in low cement alumina magnesia castable after 1200℃ treatment, The stronger effect is shown after 1600℃ treatment.

- with the increasing of magnesia, the spinel peak does not increase and some periclase peaks are found in cement free gunning mixes (G2/G3) after 1600℃ treatment.

- In this formulation design, too high content of MgO does not lead to more spinel, on the contrary, too high PLC leads to higher AP and lower strength.



After fired at 1200℃



After fired at 1600℃

Relative intensity of spinel primary peak %

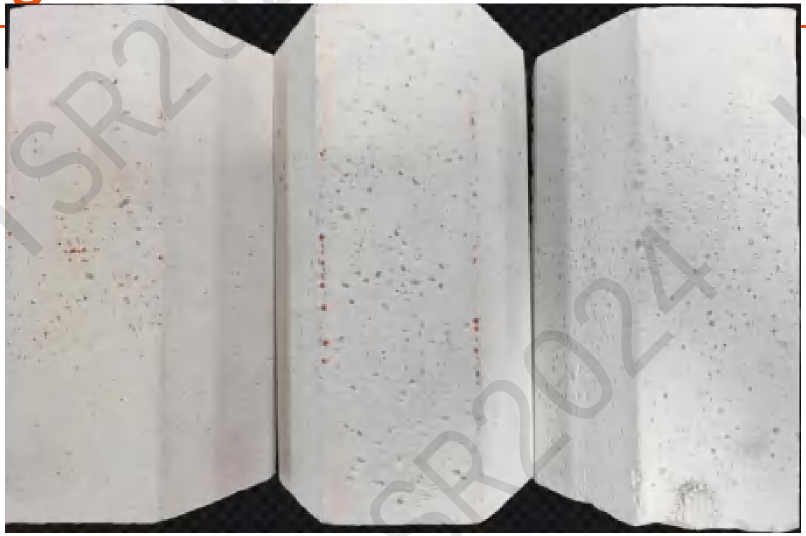
Recipe No.	G1	G2	G3	CS	CM
After 1200℃	7.2	7.5	6.1	49.2	4.7
After 1600℃	69.0	62.1	70.6	63.0	32.7

3 Result and Discussion- dynamic rotary slag test

The dynamic rotary slag resistance test procedure

1. Samples are preheated at 1000℃, and then are assembled.
2. Preparation of carbon steel and converter slag mix, the ratio is 1.5:1.
3. After the steel and slag is melted, the test temperature is hold at 1600℃ for 30 minutes.
4. Empty the melted steel and slag, repeat the step 3, the total cycle is 8.

CaO	Fe_2O_3	SiO_2	MnO	P_2O_5	Al_2O_3	MgO
47.7	26.7	5.8	4.3	2.4	11.5	1.4



200mm×(120mm/60mm)×65mm samples fired at 1000 ℃ before dynamic rotary slag test

Evaluation after dynamic rotary slag test:

- **Average corrosion rate**: R=(A-B)/A×100, where A is the original sample average thickness before the test in mm; B is the residual average thickness after the test in mm.
- **Maximum corrosion thickness**: Z_{max}=A-C, where C is the minimum residual thickness after test in mm.
- **Maximum penetration depth**: P_{max}, the maximum penetration depth of the slag in mm.

3 Result and Discussion- dynamic rotary slag test

- All the cement free dry gunning mixes perform better slag corrosion and penetration resistance.
- The increasing of magnesia delivers a relatively worse corrosion result.

Recipe No.	G1	G2	G3	CS	CM
***R* %**	13.7	13.8	16.2	22.5	20.5
Z_{max} mm	10.4	13.1	14.1	18.0	17.7
P_{max} mm	2	2	1	4	5

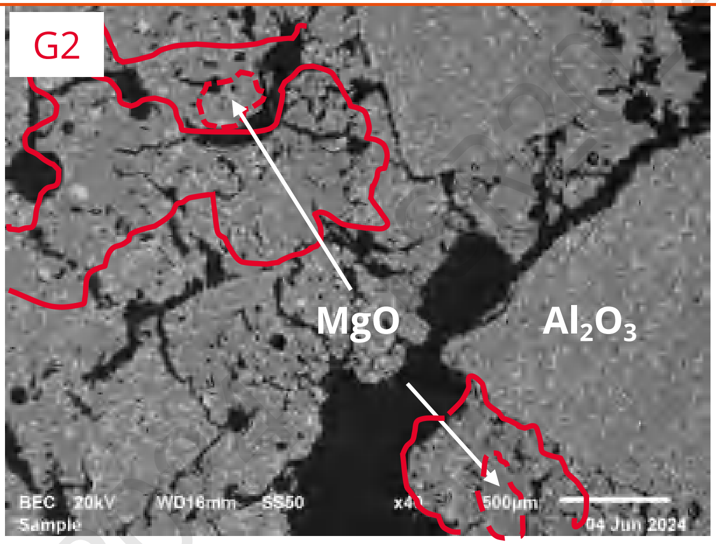
Cross section

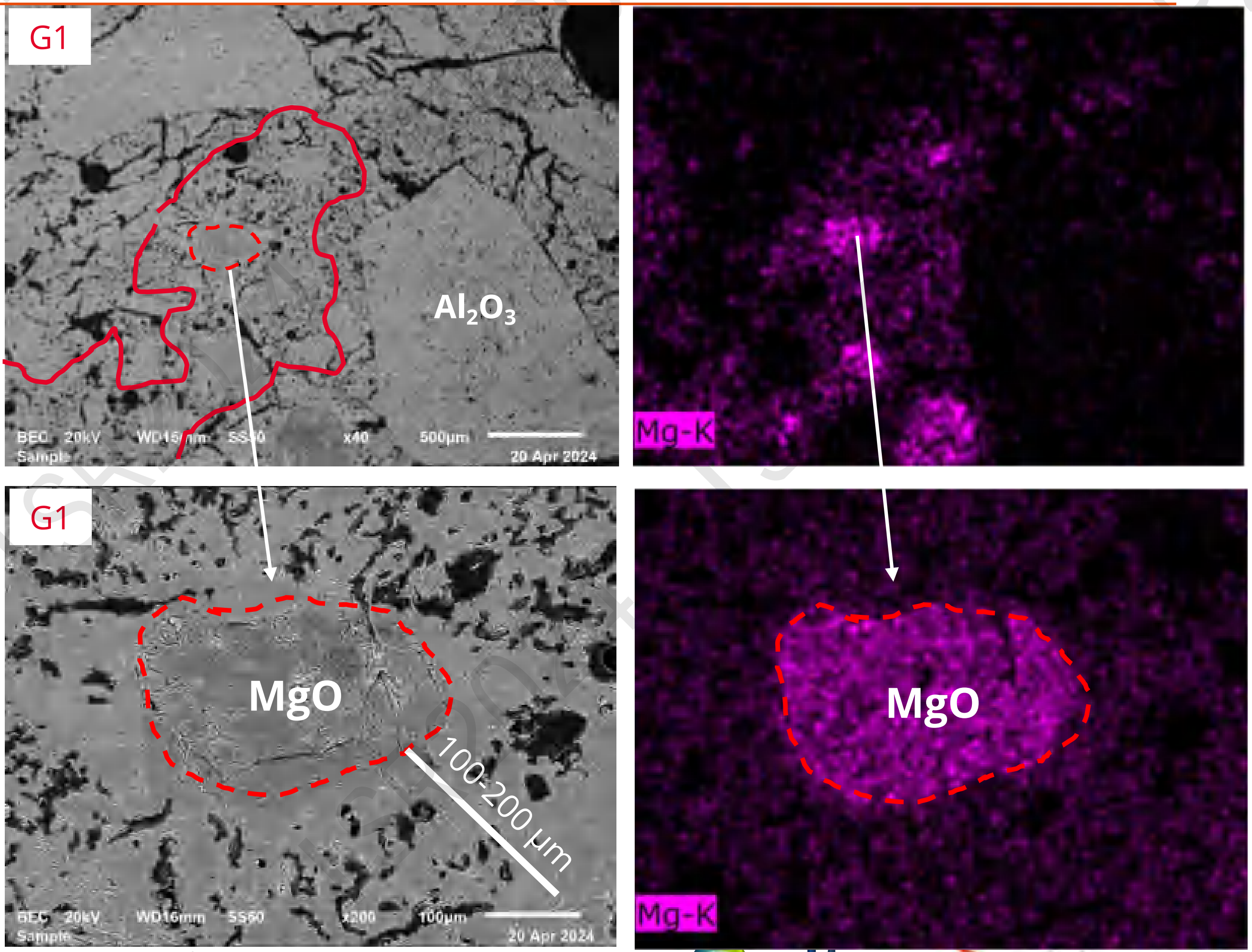
Sample position for micro analysis

Dry gunning mixes

Low cement castable

3 Result and Discussion- microstructure analysis in original zone





For cement free dry gunning mixes:

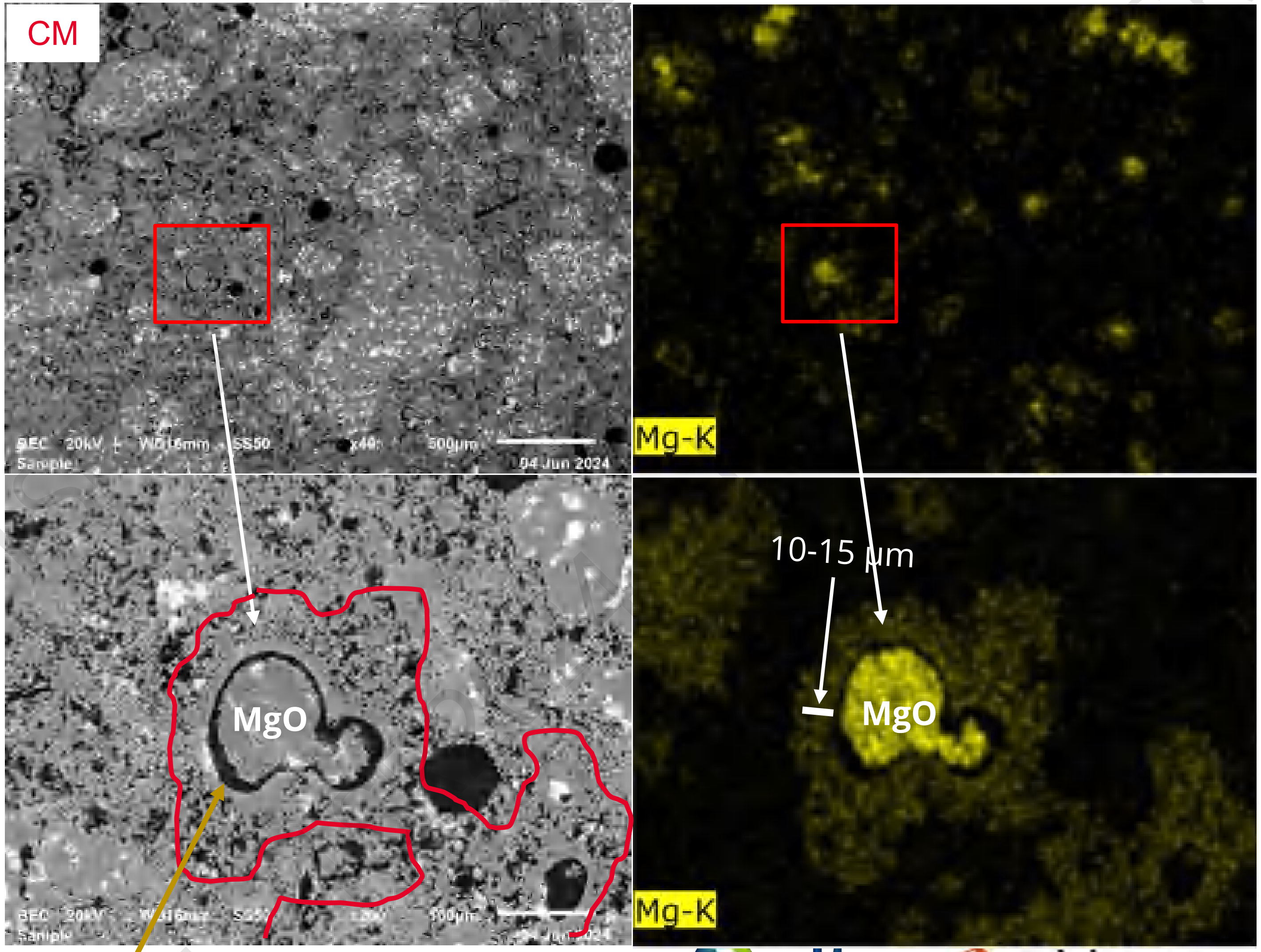
- There are more pores and cracks with the MgO increasing.

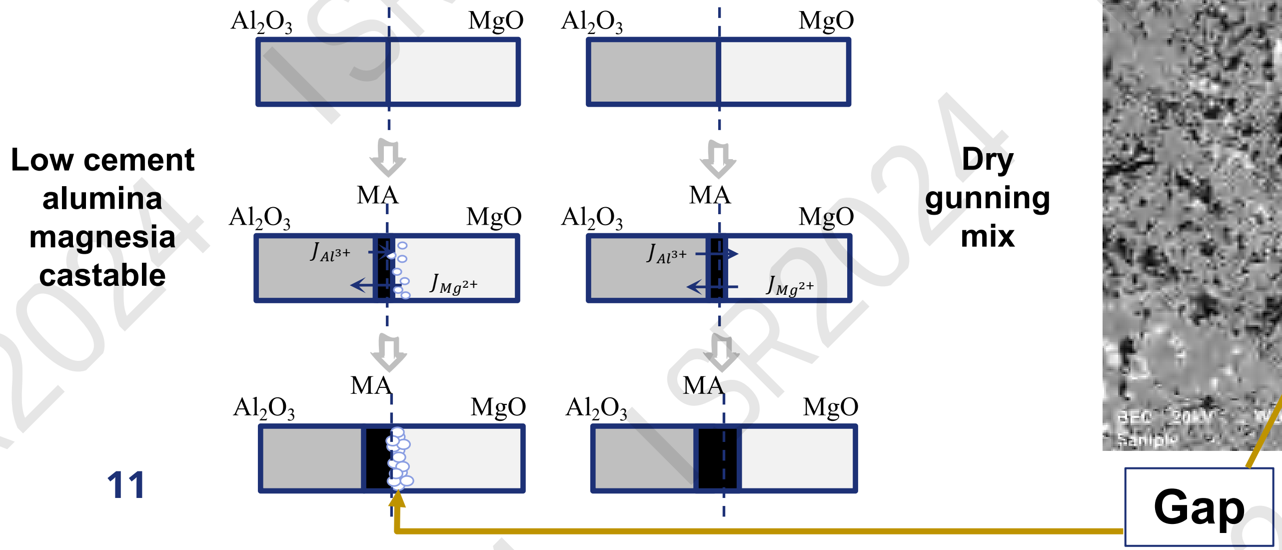
- The magnesia particles are surrounded by a 100-200 µm thick dense and continuous alumina magnesia diffusion layer, which could be considered as *in-situ* spinel.

3 Result and Discussion- microstructure analysis in original zone

For low cement alumina magnesia castable:

- The magnesia particles are surrounded by a 10-15 μm thick *in-situ* spinel layer.
- There are gaps could be found between the magnesia grain and spinel layer.
- The difference between dry gunning mixes (G1) and low cement alumina magnesia castable (CM) is in line with the previous study where indicates the difference in diffusion rates of Al^{3+} and Mg^{2+} is the main reason for this phenomenon[2].

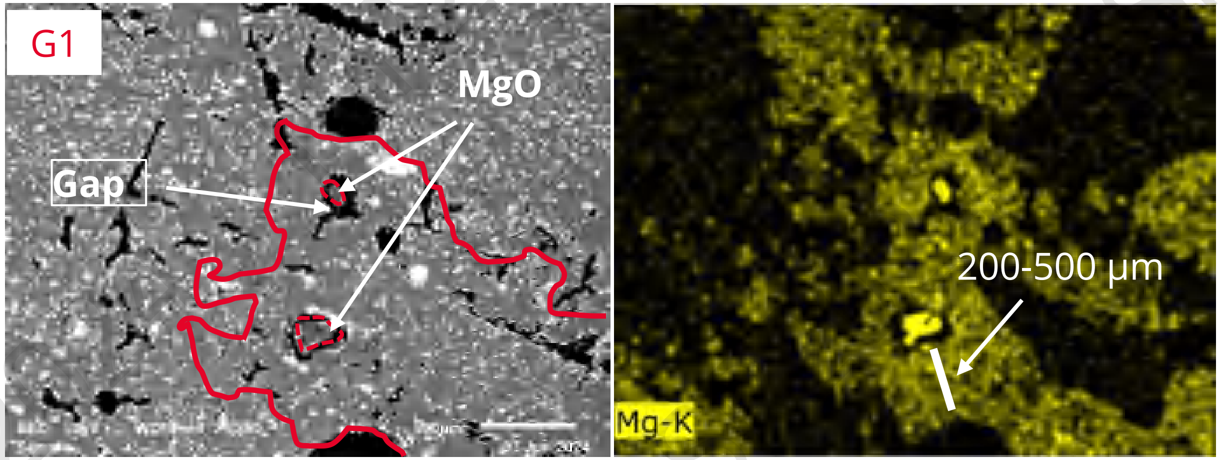


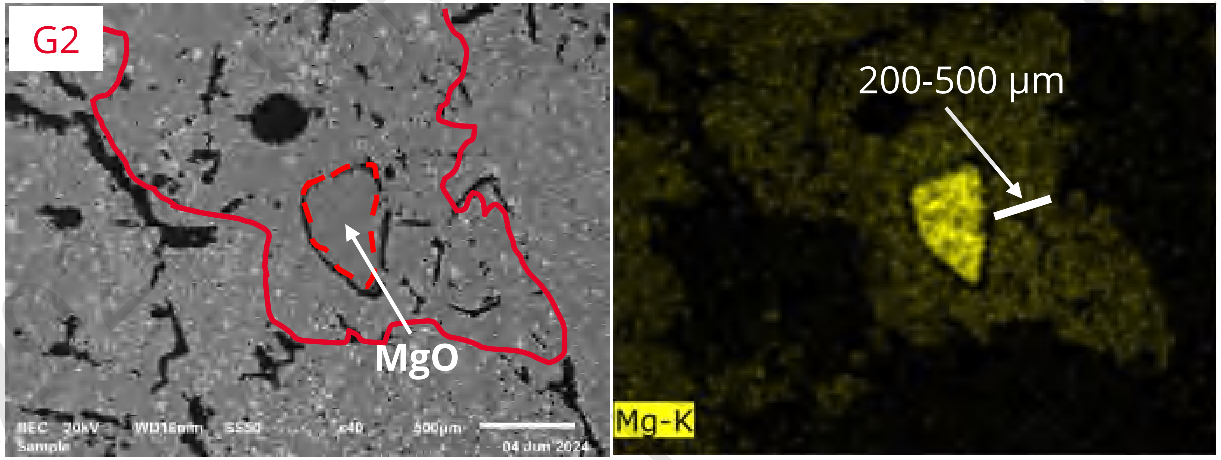


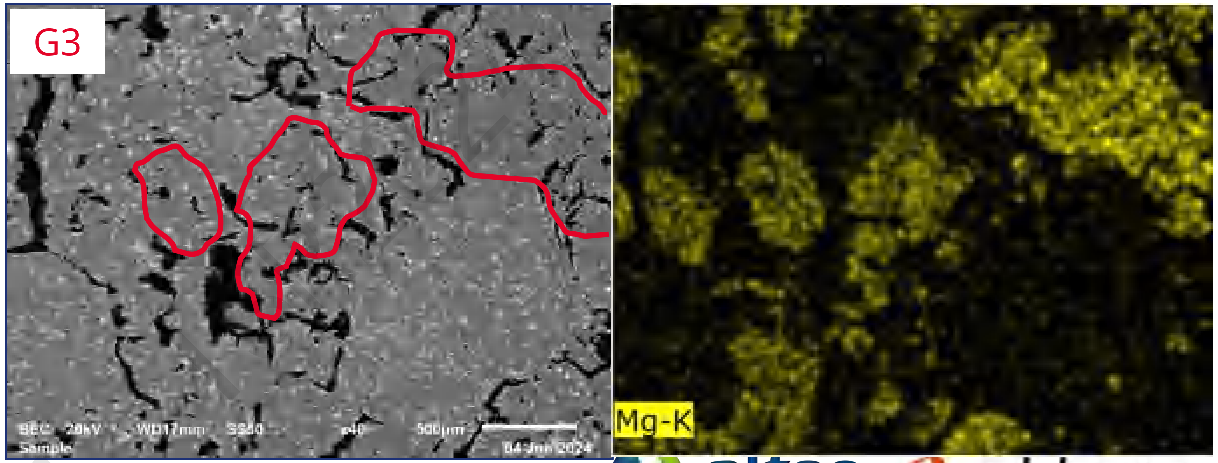
3 Result and Discussion- microstructure analysis in reaction zone

For cement free dry gunning mixes:

- There is not only large area of *in-situ* spinel formed, but also gaps found between the residue MgO particles and *in-situ* spinel layer. This might be due to the gradual consumption of MC-G.
- The diffusion distance of Mg^{2+} is between 200-500 µm.
- There are more pores and cracks with the MgO increasing.







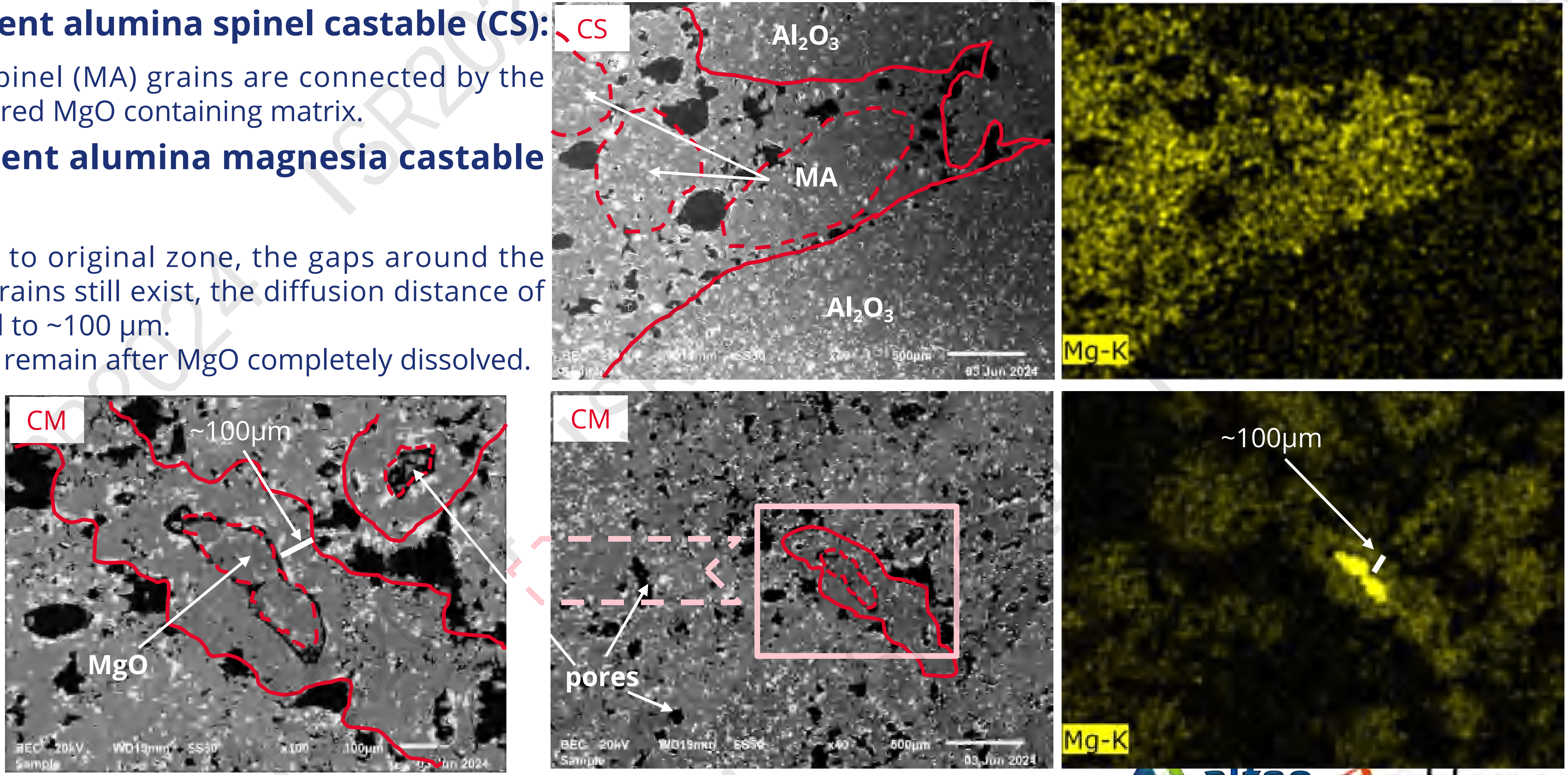
3 Result and Discussion- microstructure analysis in reaction zone

For low cement alumina spinel castable (CS):

- Al_2O_3 and spinel (MA) grains are connected by the porous sintered MgO containing matrix.

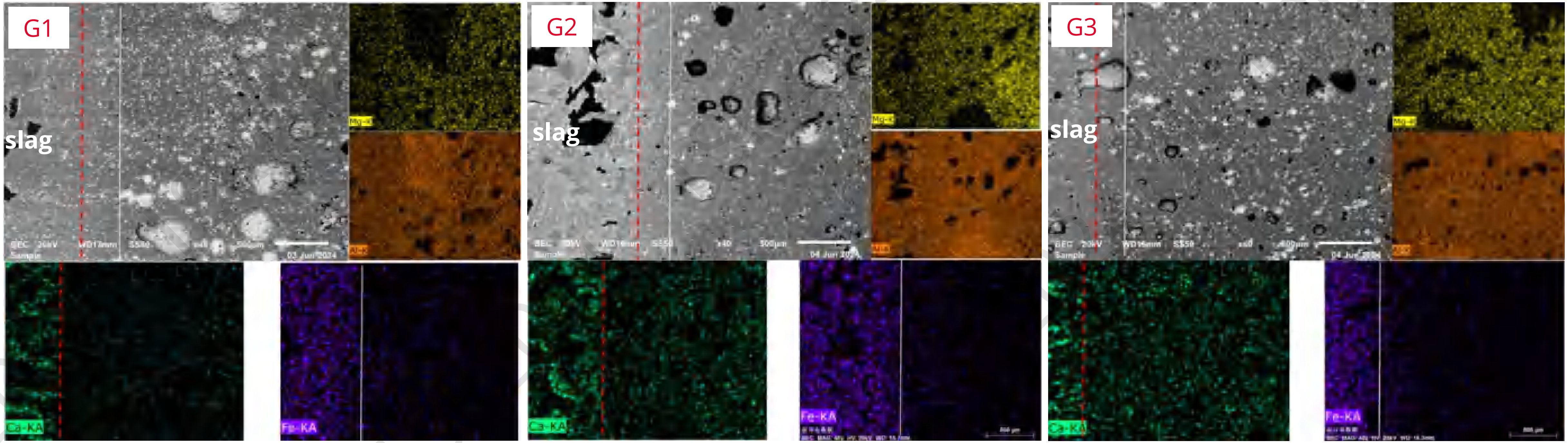
For low cement alumina magnesia castable (CM):

- Comparing to original zone, the gaps around the magnesia grains still exist, the diffusion distance of Mg^{2+} extend to ~100 μm.
- More pores remain after MgO completely dissolved.



3 Result and Discussion- microstructure analysis near slag interface

- Magnesium is homogeneously distributed in the dry gunning mixes which is indicating a sufficient diffusion and sintering.
- With the increasing of magnesia, the pores in G1, G2, G3 samples maintain the same trend as in the original zone and reaction zone.
- There is no significant difference about the penetration of Fe and Ca.



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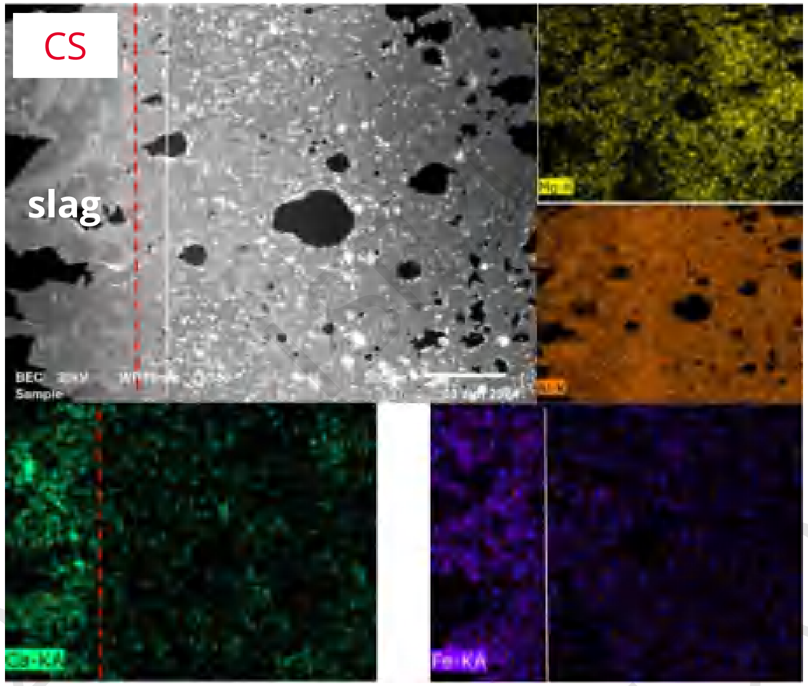
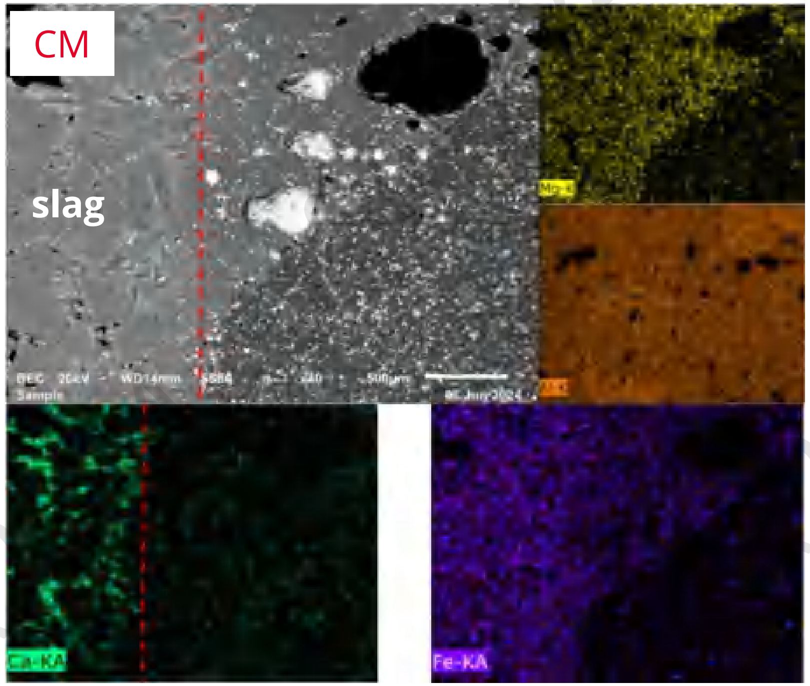
3 Result and Discussion- microstructure analysis near slag interface

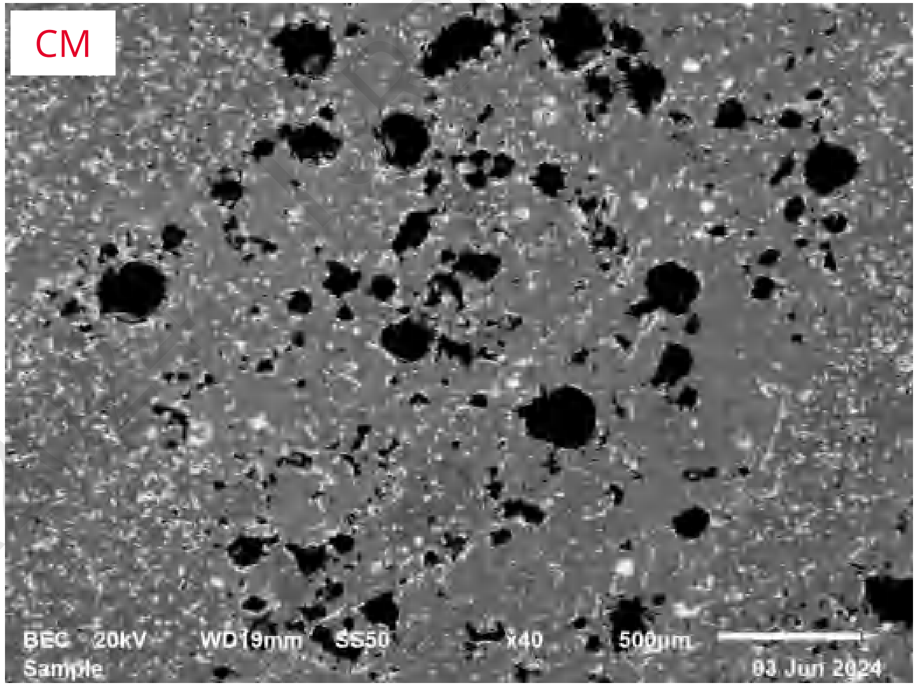
- Pores in low cement castable formula samples (CS, CM) are similar, but are larger and more than that in the dry gunning mix samples (G1, G2, G3).

- The Mg is evenly distributed in CM samples but sightly enriched in CS samples.

Away from the slag interface 1-2mm







3 Result and Discussion- discussion

The reason why dry gunning mix (G1) with lower MgO exhibits a better slag resistance than others:

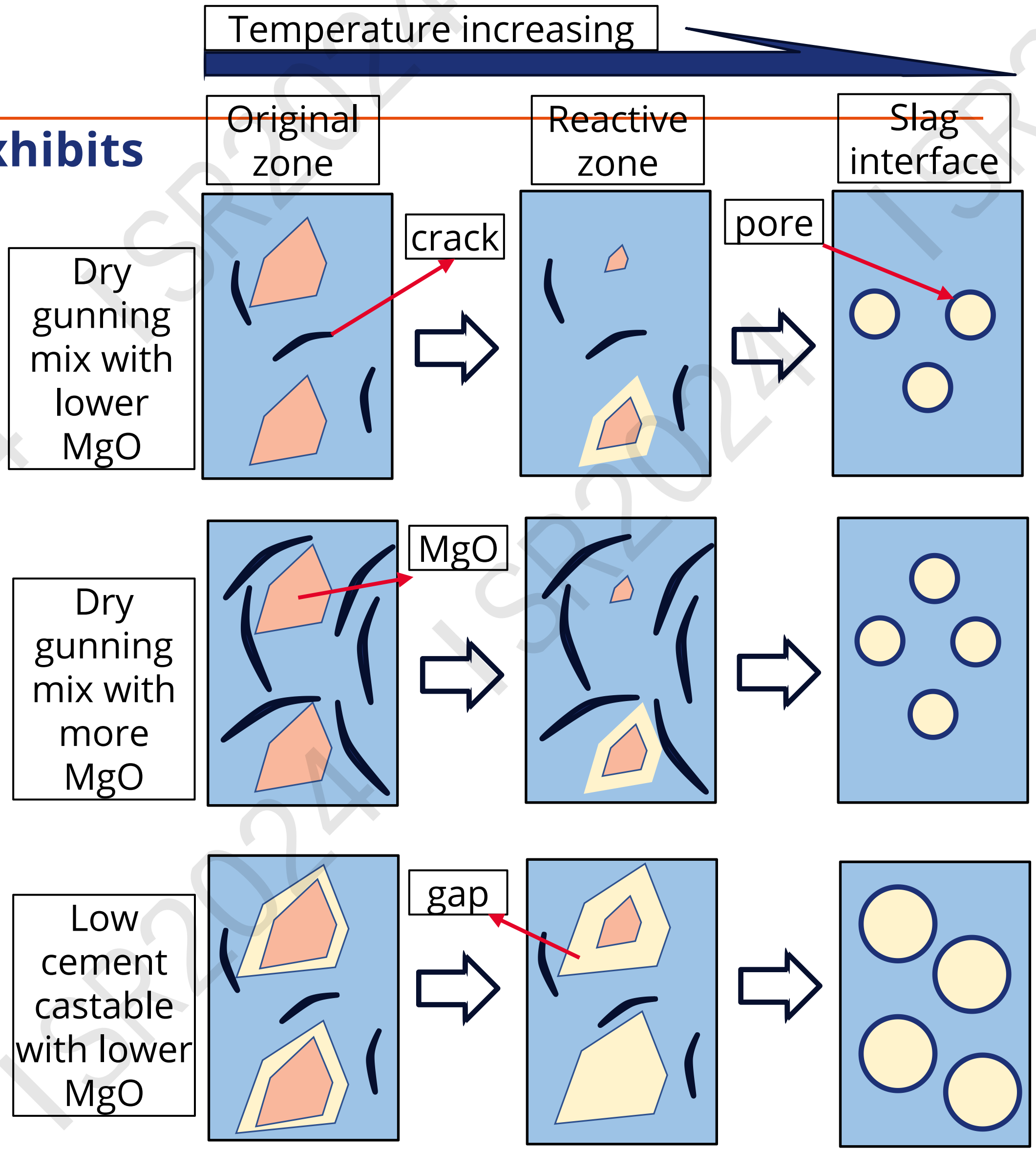
- For the dry gunning mix with low MgO content, the initial gaps and cracks are relatively small and few, due to the presence of special reactive alumina MC-G and the slight contraction in PLC.

- With the MgO increasing, higher expansion in PLC leads to longer and coarser cracks in matrix and around the Al_2O_3 particles, despite the gaps induced by MgO maintains the same as in lower MgO sample.

- For low cement castable, with the absence of MC-G, large original gaps around the MgO particles can be found early in original zone.

- All the original gaps and cracks finally incorporate into larger pores with temperature increasing. And the larger the original gaps and cracks, the more and bigger the pores are.

- As a result, the porous and loose structure near to the slag interface results in a worse dynamic rotary slag corrosion resistance.



4 Conclusions

(1) Compared with the low cement alumina spinel/magnesia castable, the cement free alumina magnesia dry gunning mixes exhibit a better dynamic rotary slag corrosion resistance. This might be due to the formation of a continuous and dense *in-situ* spinel layer induced by special reactive alumina MC-G.

(2) The increasing of MgO content, is not beneficial to slag corrosion resistance, due to the more porous and loose structure resulted by the expansion of in-situ spinel formation.

(3) In this paper, 7.5% of magnesia addition provides a better overall performance for cement free dry gunning product.

5 References

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