Presenter Name: Satyam Kumar
Paper name: Effect of fume silica reduction on the properties of alumina magnesia castable for steel ladles

PRESENT AFFILIATION	Department of Ceramic Engineering, National Institute of Technology, Rourkela-769008, Odisha, India.
AREAS OF INTEREST	Refractories, castables
Education	Ph.D. pursuing in Ceramic Engineering National Institute of Technology, Rourkela.

Experience	Teaching Experience – 8 months Research Experience- 3 years
Projects:	Study on alumina – spinel castable: preformed and insitu spinel (continuing...)
Publication/ Patent	1. *Alumina-spinel castable for steel ladles: An overview [https://doi.org/10.1111/ijac.14213]* 2. *Study on preformed and in situ spinel containing alumina castable for steel ladle: Effect of fume silica content* [https://doi.org/10.1111/ijac.14127]

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Effect of fume silica reduction on the properties of alumina magnesia castable

Satyam Kumar and Ritwik Sarkar

Department of Ceramic Engineering
National Institute of Technology
Rourkela

Introduction

- Ladles plays an important role in the transportation of molten steel. Extending the service life of the ladle not only save the production cost, but also reduce the erosion caused by molten steel on the refractories.

- The ladle refractories can be divided into four zones, including sidewall, slag line, SN tuyere and the bottom impact pad [1].

- The requirements for different zones of steel ladle are different, so it is necessary to select the right material in order to achieve a long service life [2].

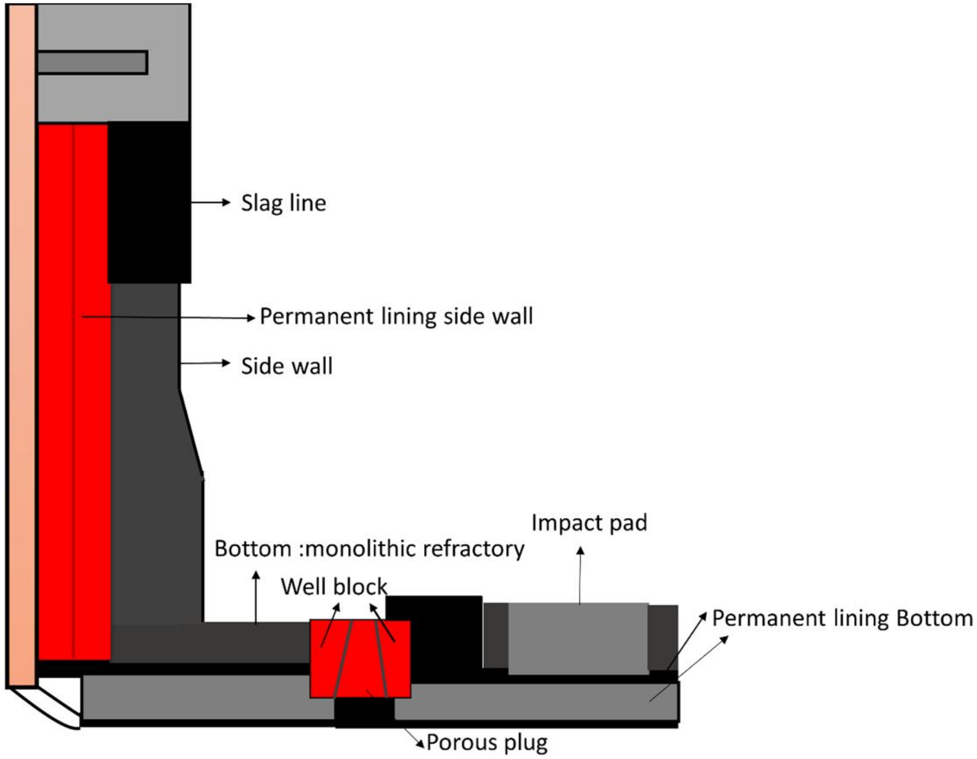

***Figure 1. Schematic diagram of steel ladle* [2]**

1. Tassot P, Andres P, Schemmel T, Sobarzo PP. Evolution of the steel ladle refractories lining in last decade. In: 47th Steelmaking Seminar – International, Rio de Janeiro, Brazil. Sept 26-30,2016;128–37
2. Kumar S, Sarkar R. Alumina spinel castable for steel ladles: An overview. International Journal of Applied Ceramic Technology. 2022 Sep 6.https://doi.org/10.1111/ijac.14213.

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Advantages of Alumina Magnesia castable :

- High Resistance to thermal shock
- Excellent hot strength
- Resistance to slag corrosion
- High thermal stability
- High mechanical strength
- High erosion resistance

Disadvantages of Alumina Magnesia castable :

- Volumetric expansion. Theoretically, this volume expansion will be 13%, based on a relative density calculation [3].
- In practice, however, this expansion is around 5%, still excessive for the microstructure to accommodate without cracking [3].
- silica fume is often used to promote liquid-phase sintering and to allow some local deformation to overcome the volume expansion [3].

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3. Racher RP, McConnell RW, Buhr A. Magnesium aluminate spinel raw materials for high-performance refractories for steel ladles. In: Proceedings of the 43rd conference of metallurgists, Hamilton, Canada. 2004 Aug 22. p. 48–53.

Experimental work

The initial raw material used in this study is white tabular alumina of different grades (WTA), fine alumina(RA), fume silica as a flow modifier, and calcium aluminate cement (CA14M Almatis, India) as the binder.

Table 1. Physico-chemical properties of raw materials

Chemical analysis/mass -%	WTA	Fine Alumina	Fused magnesia	Fume-silica	Cement
SiO_2	≤ 0.09	0.03	0.4	98.1	0.3
Al_2O_3	99.5	99.7	0.07	0.4	71
Fe_2O_3	≤ 0.02	0.04	0.22	0.1	0.2
TiO2	-	-	Trace	-	-
CaO	-	0.03	1.4	0.2	28
MgO	-	-	97.35	0.1	0.4
Na_2O+K_2O	≤ 0.40	0.1	0.26	0.4	0.3
Particle size		D_{50}=2.5 µm			
Bulk density (gm/cc)	3.61		3.44		
Apparent porosity (%)	4.8		1.88		
Sp. surface area (m^2/gm)		3.1		20	0.44
Phase analysis	Corundum	Corundum	Periclase	Amorphous	CA_2, CA

Castable batches are formulated with two different particle size distributions q = 0.21 and 0.29 using the Dinger funk equation [4] which is

$$\boxed{\text{CPFT} = \left[\frac{D^q - D_s{}^q}{D_l{}^q - D_s{}^q}\right] \times 100}$$

Here, CPFT= Cumulative percent finer than, D = particle size, D_s = minimum particle size and D_l = maximum particle size and q = distribution coefficient.

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4. Dinger DR, Funk JE. Particle packing. III: Discrete versus continuous particle sizes. Interceram. 1992;41(5):332–4.

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Table 2. Batches prepared with fume silica 4 wt.% and 1 wt.%

Material/ Batch- q value	1 0.21	2 0.29	3 0.21	4 0.29	5 0.21	6 0.29	7 0.21	8 0.29
WTA	70.8	77.0	70.8	77.0	70.8	77.0	70.8	77.0
Fine alumina	17.9	11.7	15.1	8.94	20.9	14.7	18.1	11.94
Fused magnesia	2.8	2.8	5.6	5.6	2.8	2.8	5.6	5.6
Cement	4	4	4	4	4	4	4	4
Fume silica	**4**	**4**	**4**	**4**	**1**	**1**	**1**	**1**
Dispersant	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Citric acid	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Water	8	7.2	8	7.8	8.4	8.2	8	7.8

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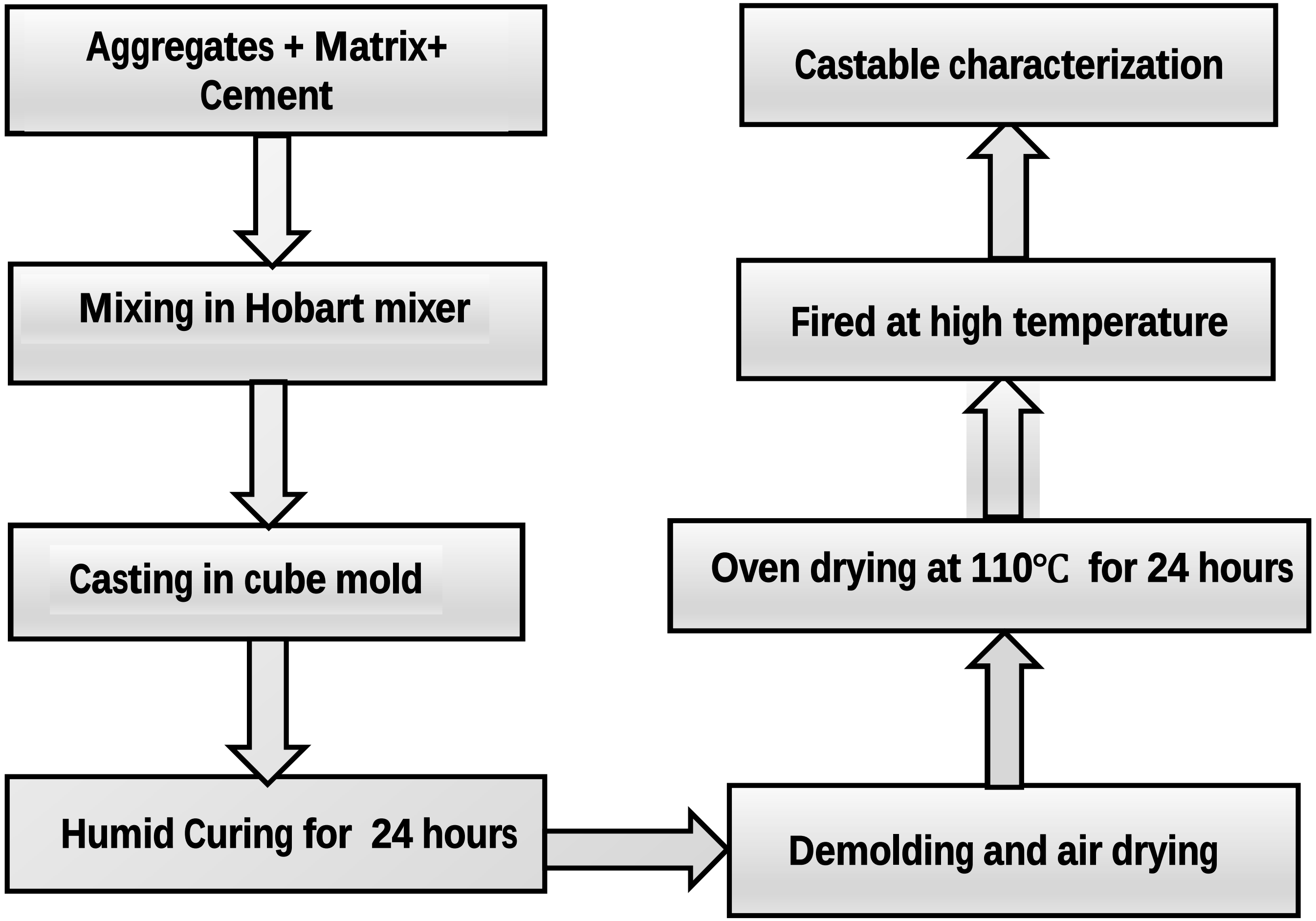


Aggregates + Matrix+ Cement

Mixing in Hobart mixer

Casting in cube mold

Humid Curing for 24 hours

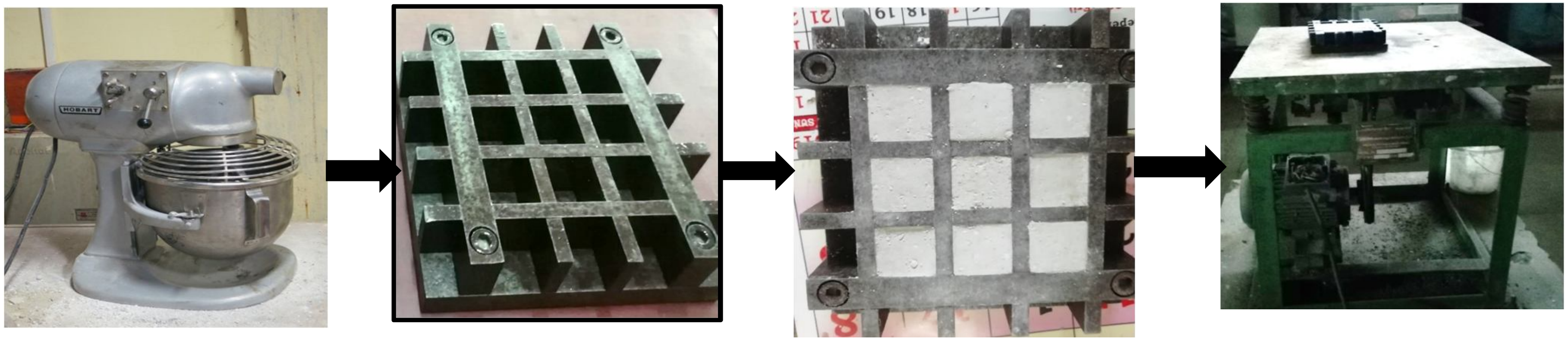
Demolding and air drying

Oven drying at 110℃ for 24 hours

Fired at high temperature

Castable characterization

Figure 2. Flow chart of castable making process



1. Hobart Mixture

2. Cubical mold after fixing

3. Casting

4. Vibratory table

4. Samples at 1000 ºc

5. Samples at 1550 ºc

6.samples

7. CCS machine

Figure 3. Castable Making Process

Results and discussions

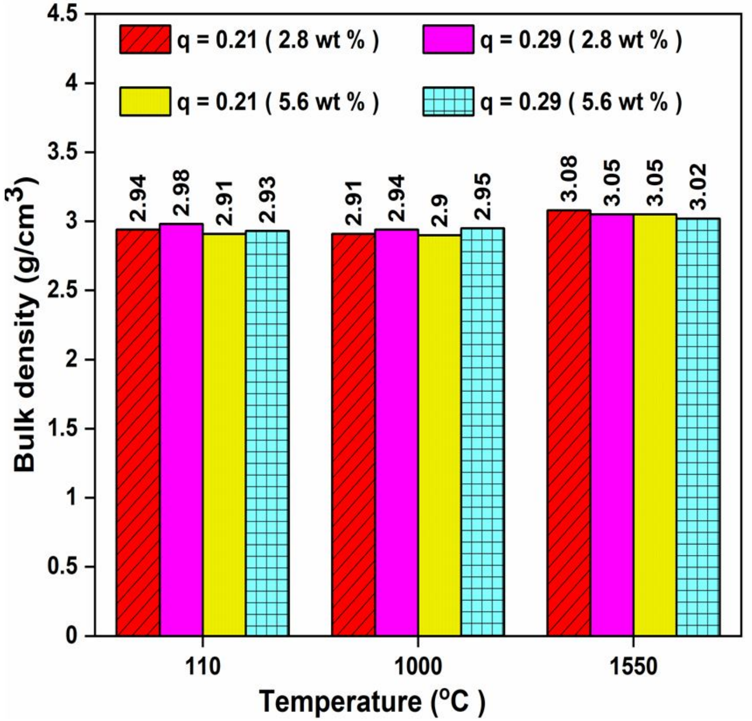


Figure. 4

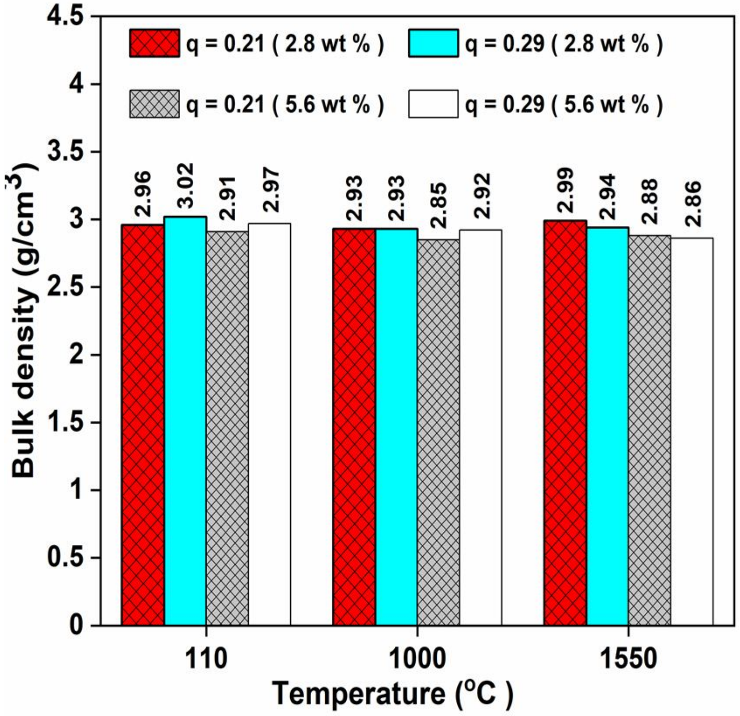


Figure. 5

- The specific gravity of alumina is higher than spinel, so replacing the higher-density material with lower-density material has reduced the density values [6].
- Density values for all the compositions are found to be decreasing with an increase in temperature from 110 to 1000 °C [7-8].

BD of compositions with variation in fume silica content

5. Kumar S, Sarkar R. Study on preformed and in situ spinel containing alumina castable for steel ladle: Effect of fume silica content. International Journal of Applied Ceramic Technology. 2022 Jul 24. https://doi.org/10.1111/ijac.14127 .

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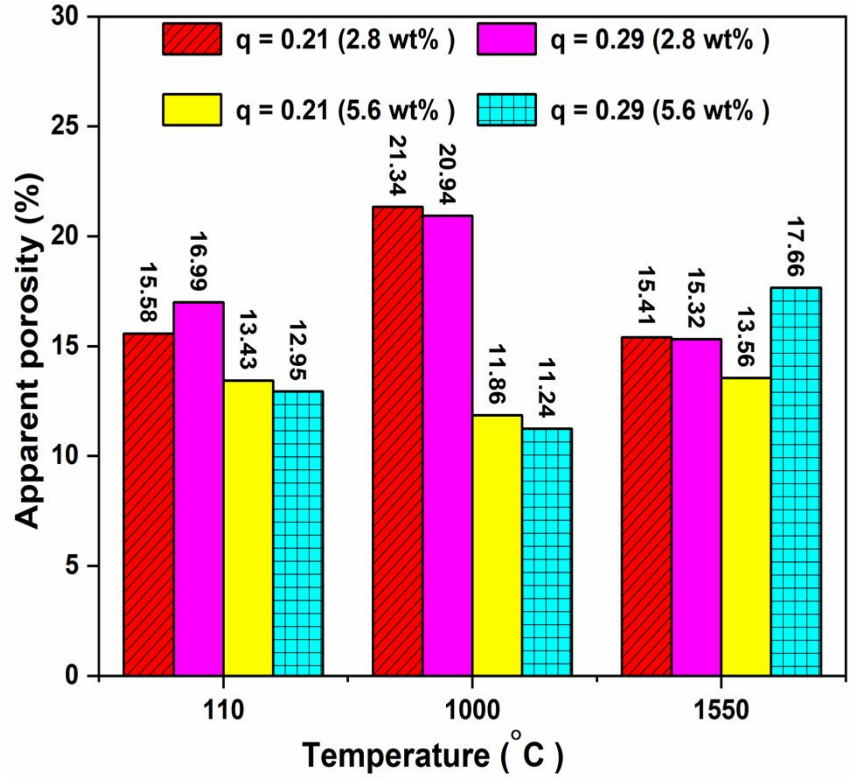

Figure. 6

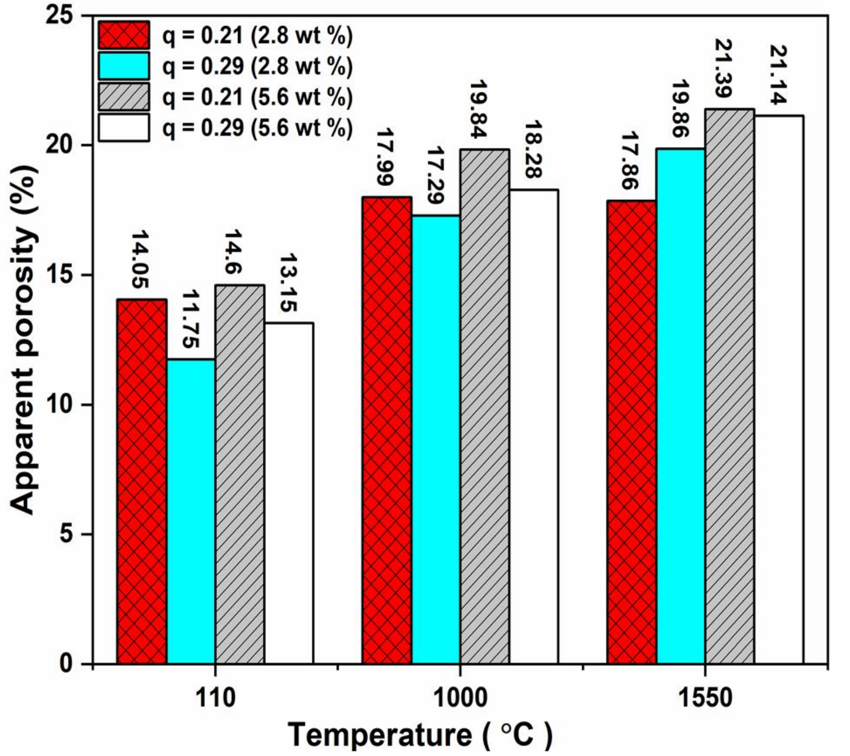

Figure. 7

Apparent porosity of the composition with variation in fume silica content

5. Kumar S, Sarkar R. Study on preformed and in situ spinel containing alumina castable for steel ladle: Effect of fume silica content. International Journal of Applied Ceramic Technology. 2022 Jul 24. https://doi.org/10.1111/ijac.14127.

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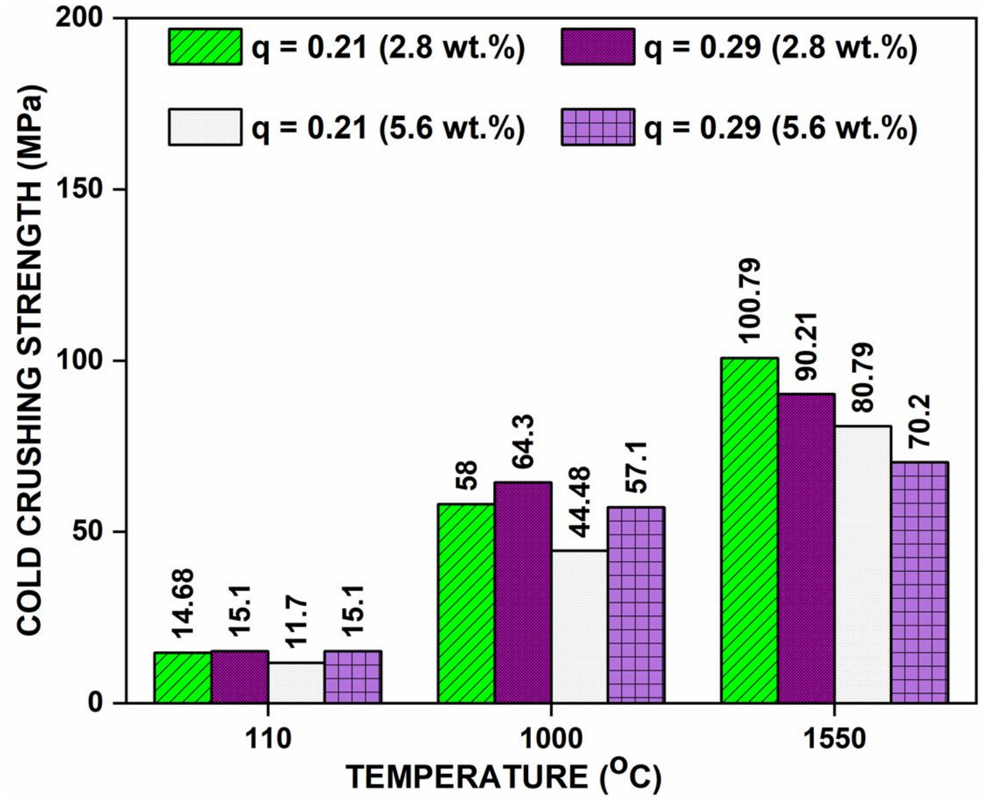

Figure. 8

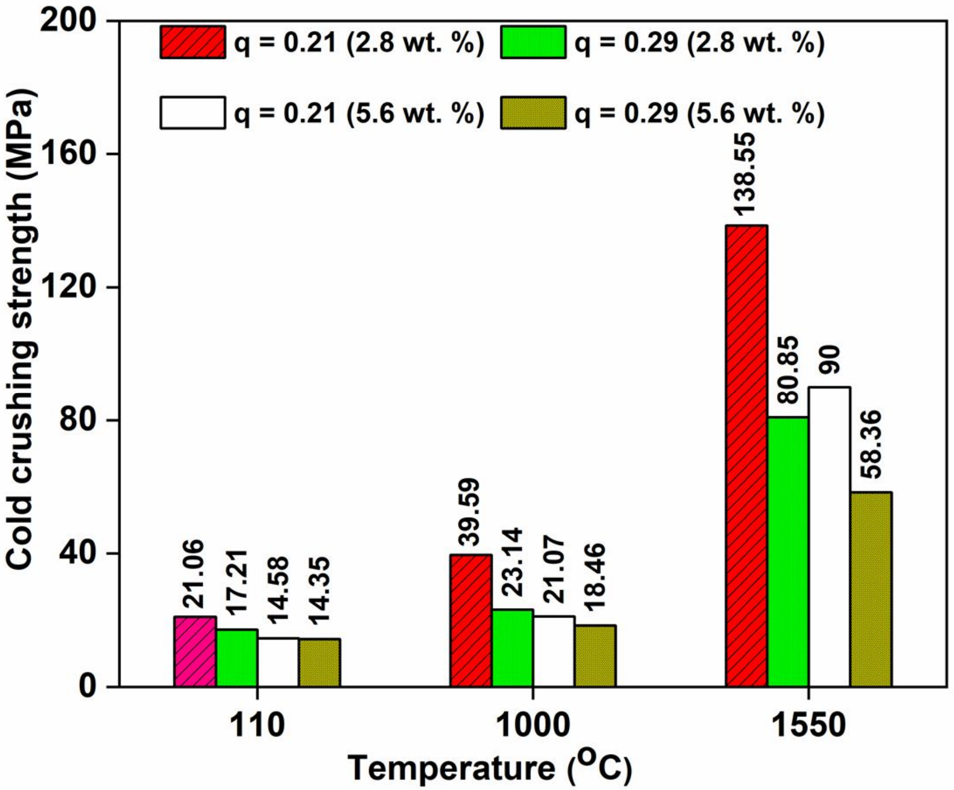

Figure. 9

CCS of compositions with variation in fume silica content

5. Kumar S, Sarkar R. Study on preformed and in situ spinel containing alumina castable for steel ladle: Effect of fume silica content. International Journal of Applied Ceramic Technology. 2022 Jul 24. https://doi.org/10.1111/ijac.14127 .

Phase analysis:

Phase analysis of matrix part of alumina magnesia castable with 4wt.% fume silica addition was done by powder x-ray diffraction (XRD) technique.

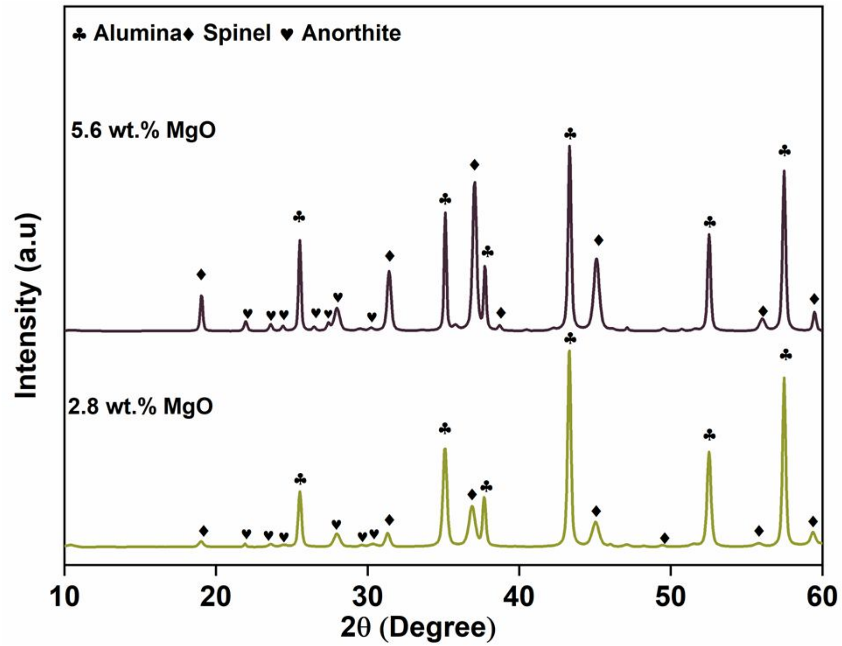

Figure10. Phase analysis of the matrix part q = 0.21 MgO 2.8 and 5.6 &Fume silica 4wt.%

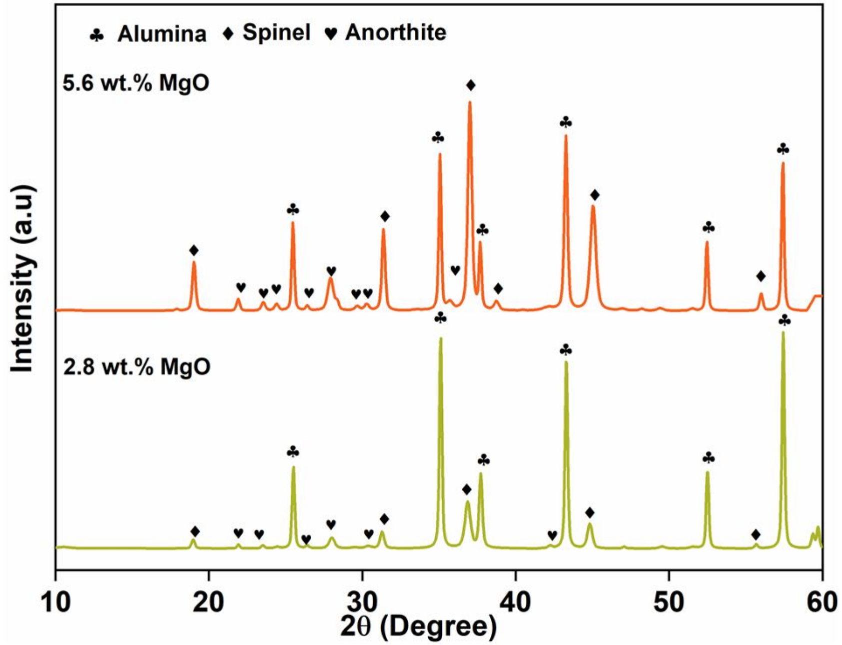

Figure 11. Phase analysis of the matrix part q = 0.29 MgO 2.8 and 5.6 &Fume silica 4wt.%

5. Kumar S, Sarkar R. Study on preformed and in situ spinel containing alumina castable for steel ladle: Effect of fume silica content. International Journal of Applied Ceramic Technology. 2022 Jul 24. https://doi.org/10.1111/ijac.14127 .

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- Hibonite phase is formed due to reaction between fine alumina and high alumina cement. This is a desired refractory phase due to its needle like shape and chemical stability and has capability to improve thermal shock resistance and corrosion resistance [9].

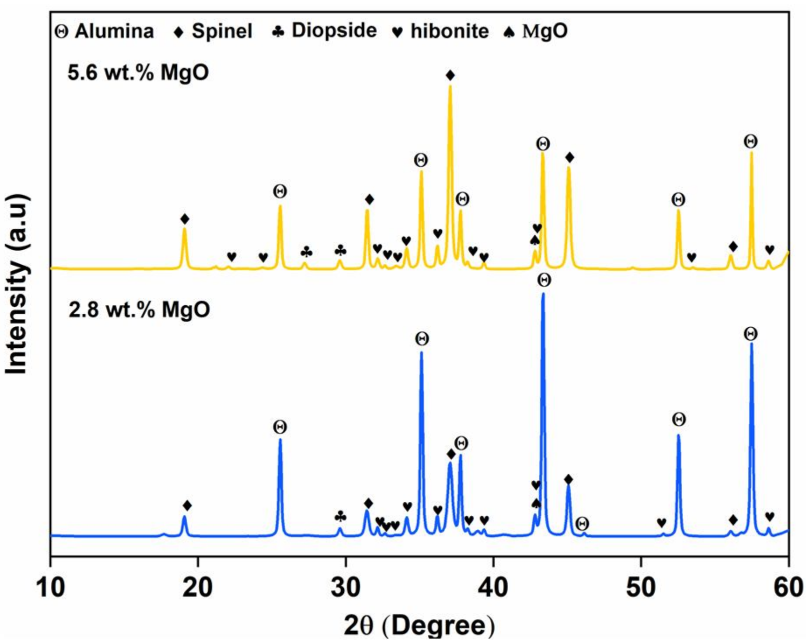


Figure 12. Phase analysis of the matrix part q = 0.21 MgO 2.8 and 5.6 &Fume silica 1 wt.%

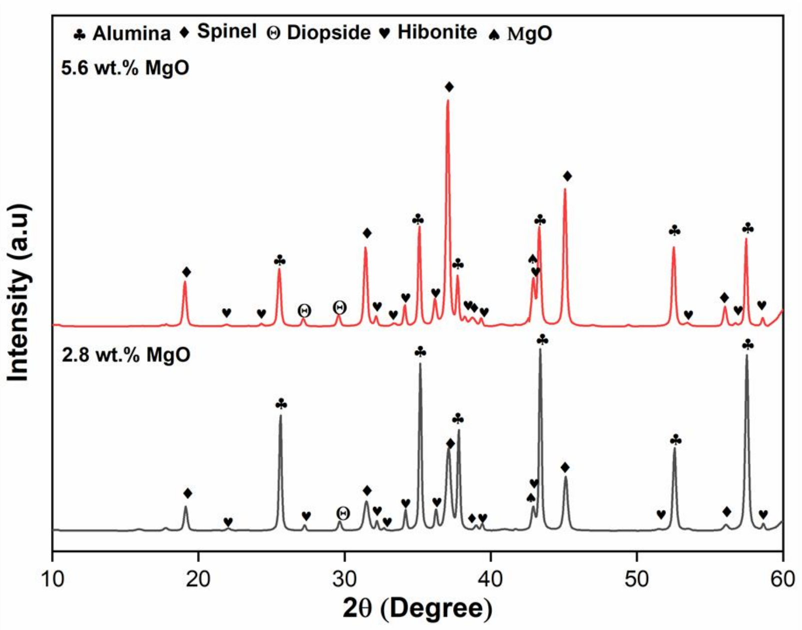


Figure 13. Phase analysis of the matrix part q = 0.29 MgO 2.8 and 5.6 &Fume silica 1wt.%

5. Kumar S, Sarkar R. Study on preformed and in situ spinel containing alumina castable for steel ladle: Effect of fume silica content. International Journal of Applied Ceramic Technology. 2022 Jul 24. https://doi.org/10.1111/ijac.14127 .

Hot strength study:

Hot modulus of rupture (HMOR) test is performed on the bar shaped samples fired at 1550°C of all the compositions by 3-point bending technique at 1400°C in air atmosphere.

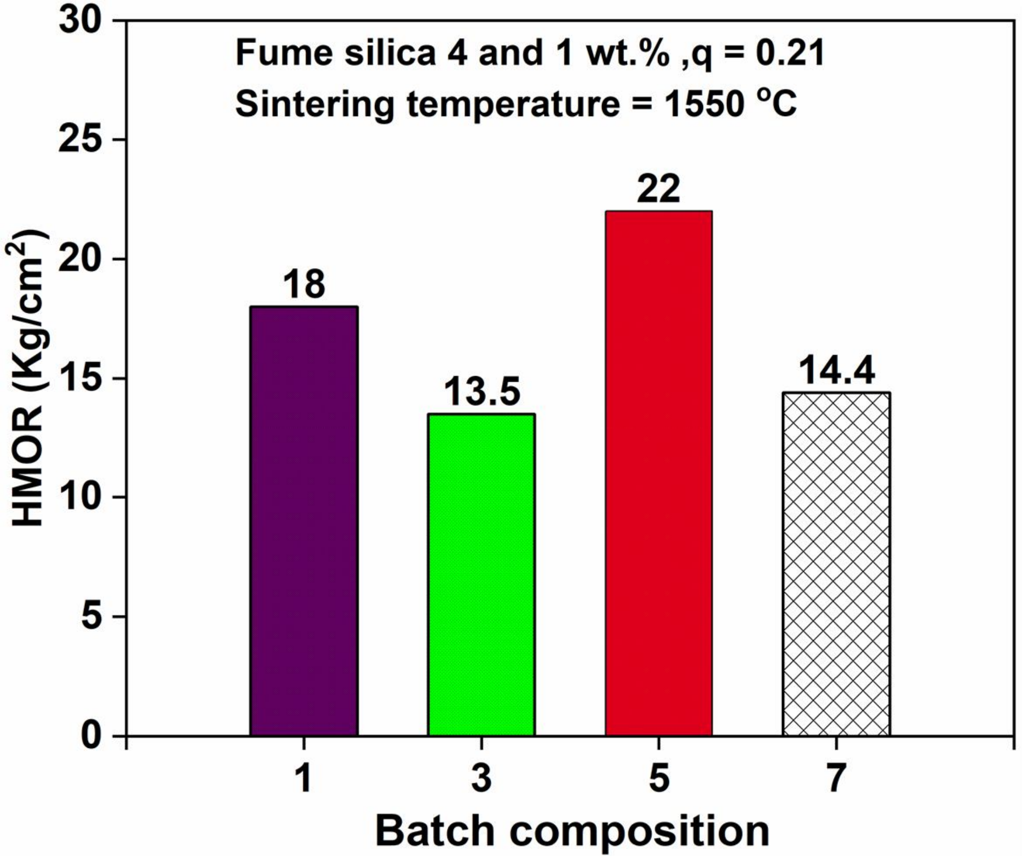
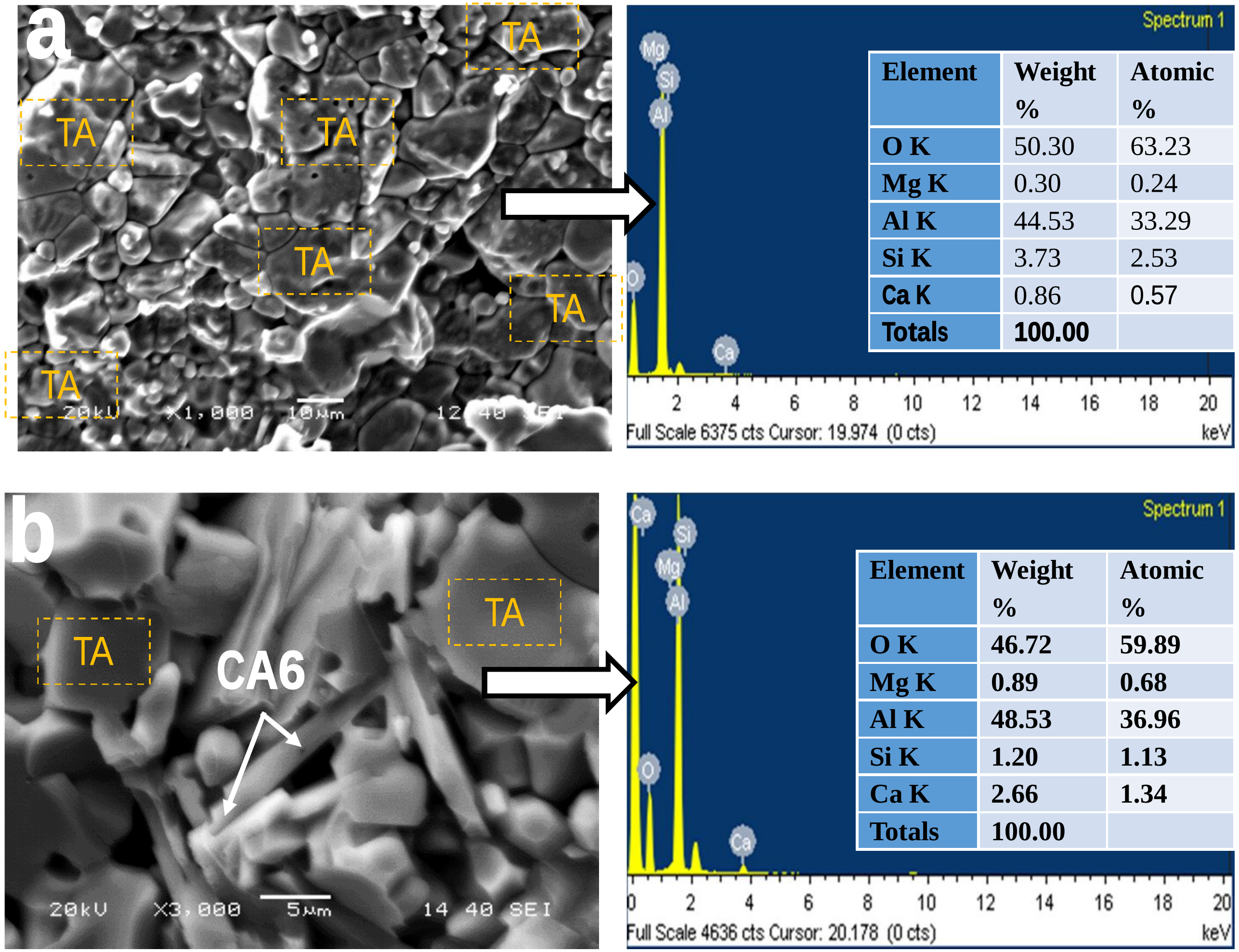


Figure 14. Hot strength of the batch composition

- ❖ Reduction in fume silica content from 4 wt.% to 1 wt.% has improved the hot strength values for in-situ spinel castables.
- ❖ Greater extent of ceramic bonding between aggregate phase and matrix phase also responsible for improving hot strength.

5. Kumar S, Sarkar R. Study on preformed and in situ spinel containing alumina castable for steel ladle: Effect of fume silica content. International Journal of Applied Ceramic Technology. 2022 Jul 24. https://doi.org/10.1111/ijac.14127 .

Microstructural and EDS analysis :



Element	Weight %	Atomic %
O K	50.30	63.23
Mg K	0.30	0.24
Al K	44.53	33.29
Si K	3.73	2.53
Ca K	0.86	0.57
Totals	100.00	

Element	Weight %	Atomic %
O K	46.72	59.89
Mg K	0.89	0.68
Al K	48.53	36.96
Si K	1.20	1.13
Ca K	2.66	1.34
Totals	100.00	

Figure 15 (a & b). Micrographs of alumina magnesia castable batches with fume silica content of 4 wt.% and 1 wt.%

- ❖ Plate-like morphology is observed in the microstructure. This Plate-like structure is calcium hexa aluminate. This CA_6 phase was not seen when fume silica content was 4 wt.% however, low melting phase anorthite was observed.

- ❖ The CA_6 phase helped in the formation of a better interlocking structure between matrix and aggregate phase which is favourable for the better hot strength properties

5. Kumar S, Sarkar R. Study on preformed and in situ spinel containing alumina castable for steel ladle: Effect of fume silica content. International Journal of Applied Ceramic Technology. 2022 Jul 24. https://doi.org/10.1111/ijac.14127.

Conclusions:

- *The bulk density value is higher with 4 wt.% fume silica content for both q values 0.21 and 0.29.*
- *Cold crushing strength value is higher for 1 wt.%. fume silica batches with MgO addition 2.8 wt.% with a distribution coefficient value of 0.21.*
- *A low melting anorthite phase was observed with 4 wt.% fume silica addition, but the hibonite phase was observed with 1 wt.% fume silica content.*
- *Micrographs study shows platy-like crystal structure with 1 wt.% fume silica batches.*
- *The system has a lower hot strength value with higher fume silica content due to low melting phase formation.*

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Thank

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