Effect of Al_2O_3/SiO_2 on the structure and properties of porous forsterite-spinel-periclase ceramics

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China has promised to reach the peak of CO_2 emissions before 2030 and strive to achieve carbon neutrality before 2060. Energy conservation, emission reduction and improvement of thermal efficiency are ways to achieve "carbon neutrality".

The world is hungry for ENERGY

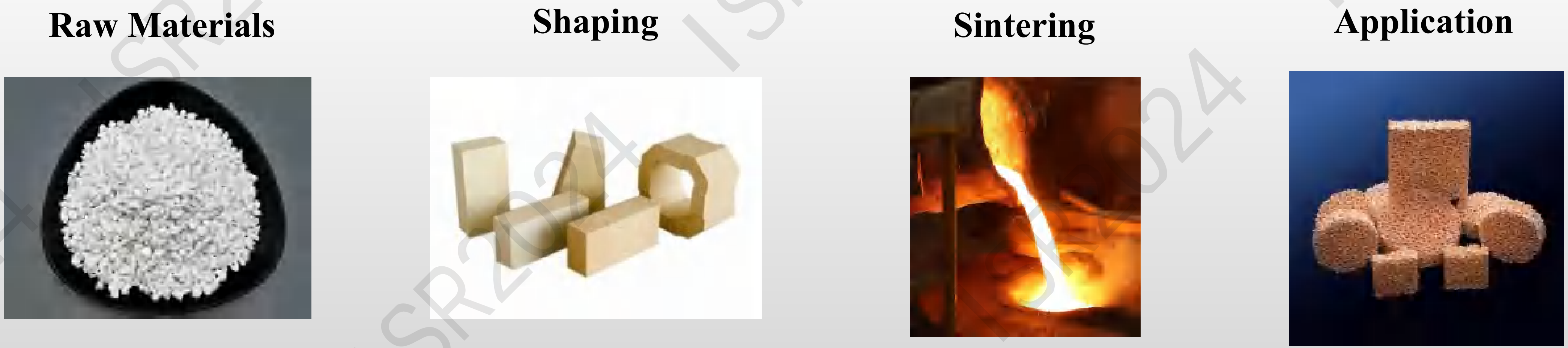


Fig. 1 Current status of refractory materials technology

01 Research Background

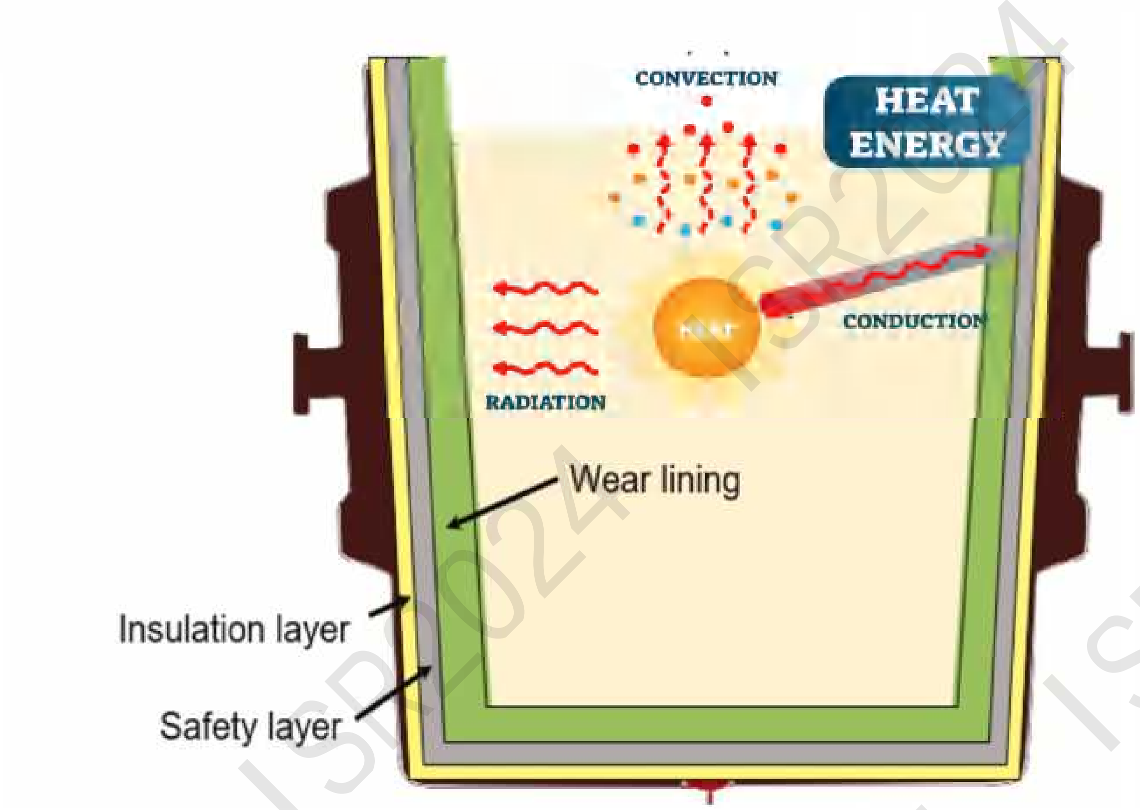


Fig. 2 Conventional structure of a high-temperature industrial furnace [1].

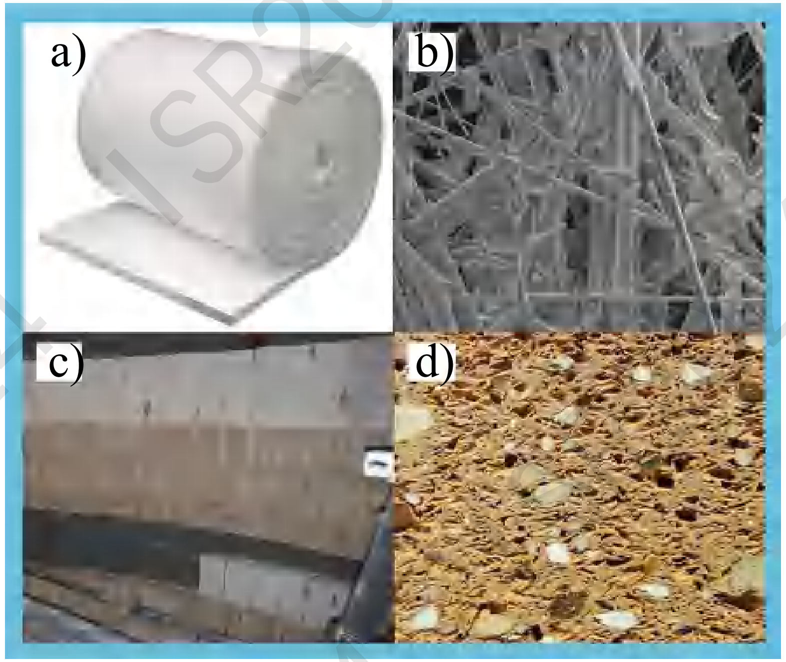


Fig. 3 Examples of two different classes of porous ceramics used as high-temperature thermal insulators [2].

The heat storage loss of the furnace lining and the heat dissipation from the surface of the furnace body account for 1/4 to 1/2 of the total fuel consumption of industrial furnaces, resulting in significant heat loss in thermal furnaces.

[1] Fu, L., et al. Journal of the European Ceramic Society 42(3): 744-763.
[2] SALOMãO R et al. Interceram - International Ceramic Review, 2021, 70(3): 38-45.

02 Research Method

We use a novel method to fabricate **Porous Forsterite-Spinel-Periclase Ceramics(M-M2S-MA).**

Transient Liquid Phase Diffusion Process

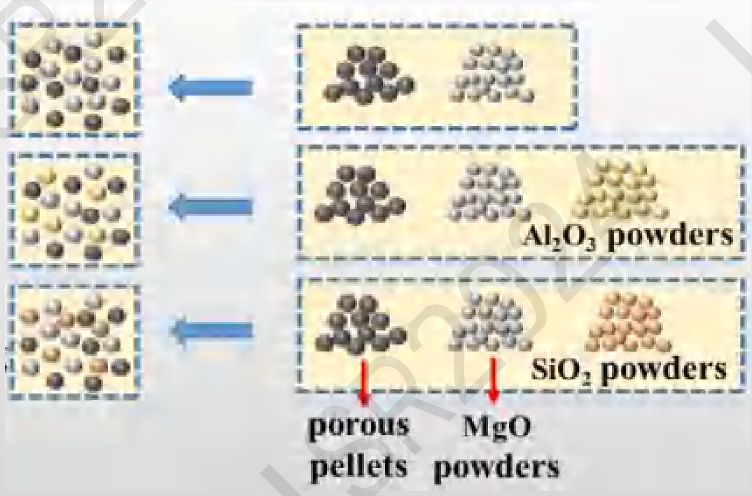
1. Fabricating porous pellets S1.
2. Adding S1 to the matrix to get MAS1/S1A/S1S.
3. Sintering.

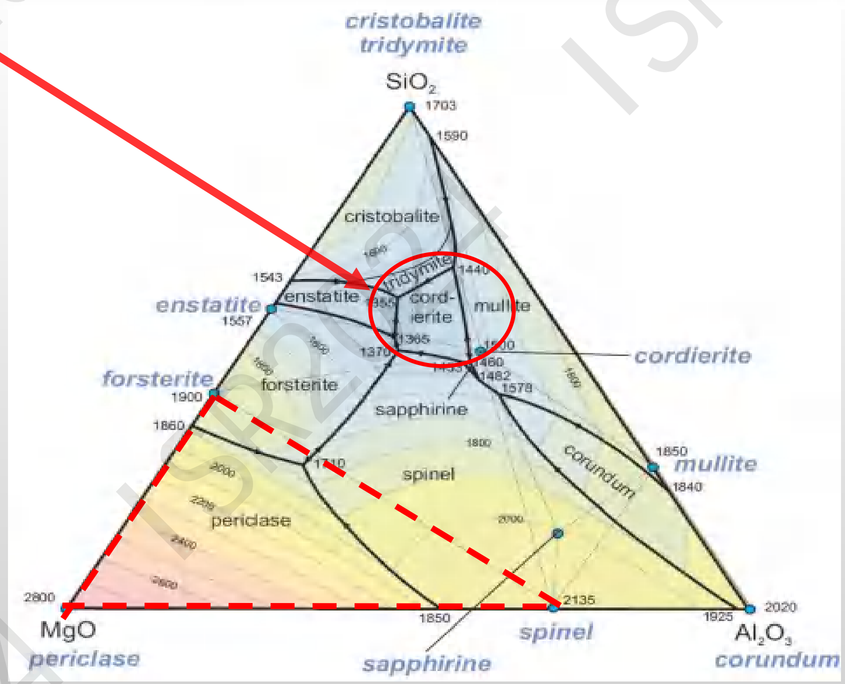
Materials	S1	Fused magnesia powder	α-Al_2O_3	Quartz powder
MAS1	40	60	—	—
S1A	40	46.5	13.5	—
S1S	40	52	—	8

MAS1

S1A

S1S





Preparation Process

03 Experimental Results

Phase Evolution

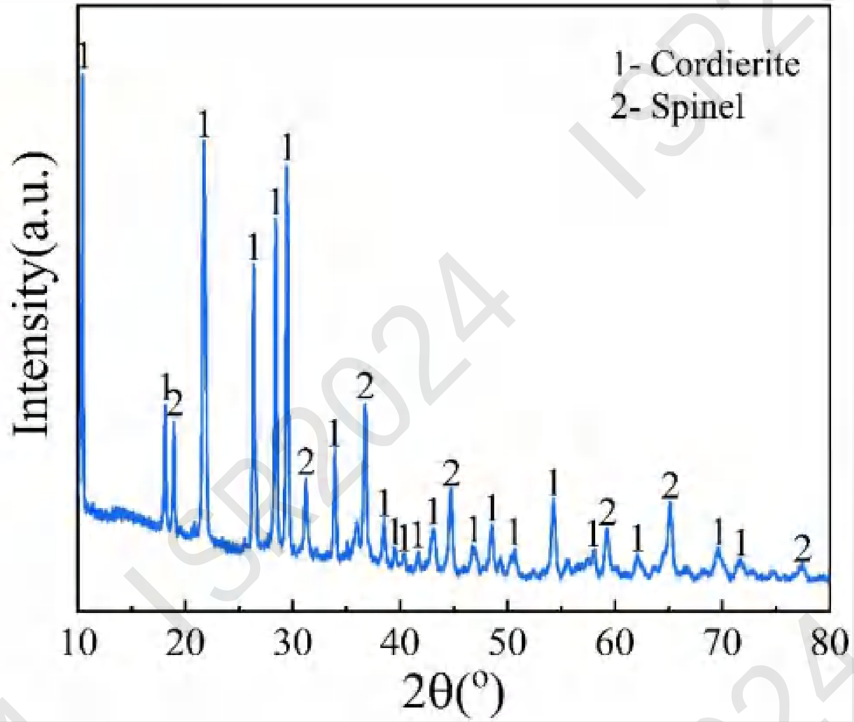


Fig. 5 XRD patterns of S1 pellet calcined at 1350 °C for 2 h.

Table 1 Chemical composition of raw materials (wt%).

Sample no.	Composition of raw materials / wt%		
	$4MgCO_3$•$Mg(OH)_2$•5H_2O	$Al(OH)_3$	SiO_2
S1	26	38	36

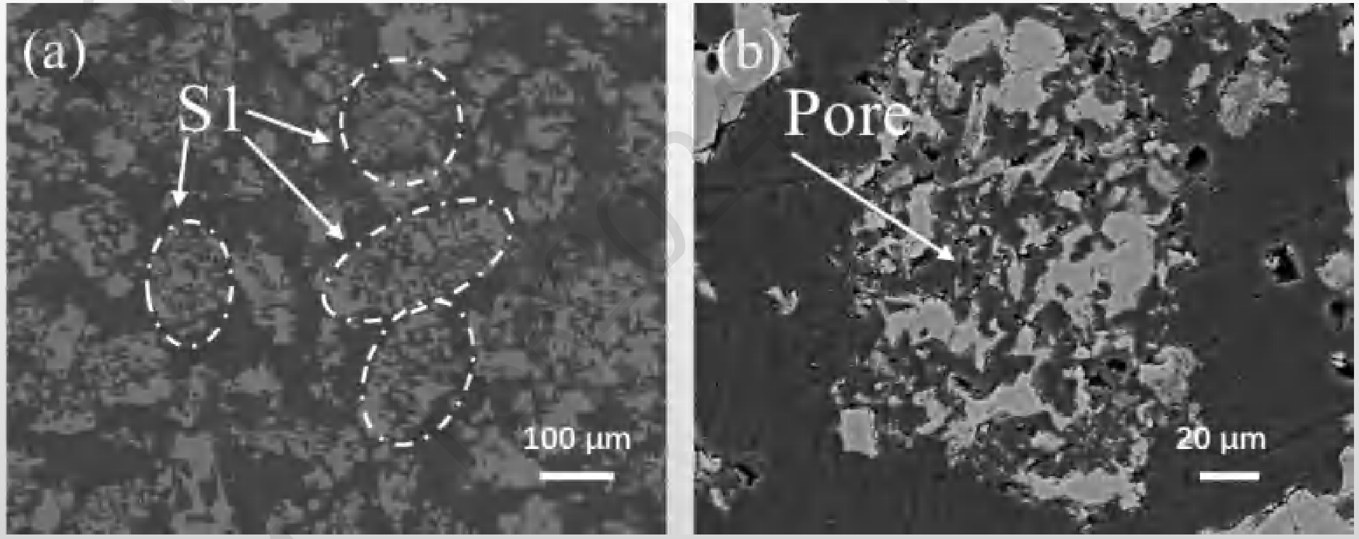


Fig. 6 SEM results of S1 pellet calcined at 1350 °C for 2 h.

Phase transformation of pore formation process of S1A, S1S, MAS1

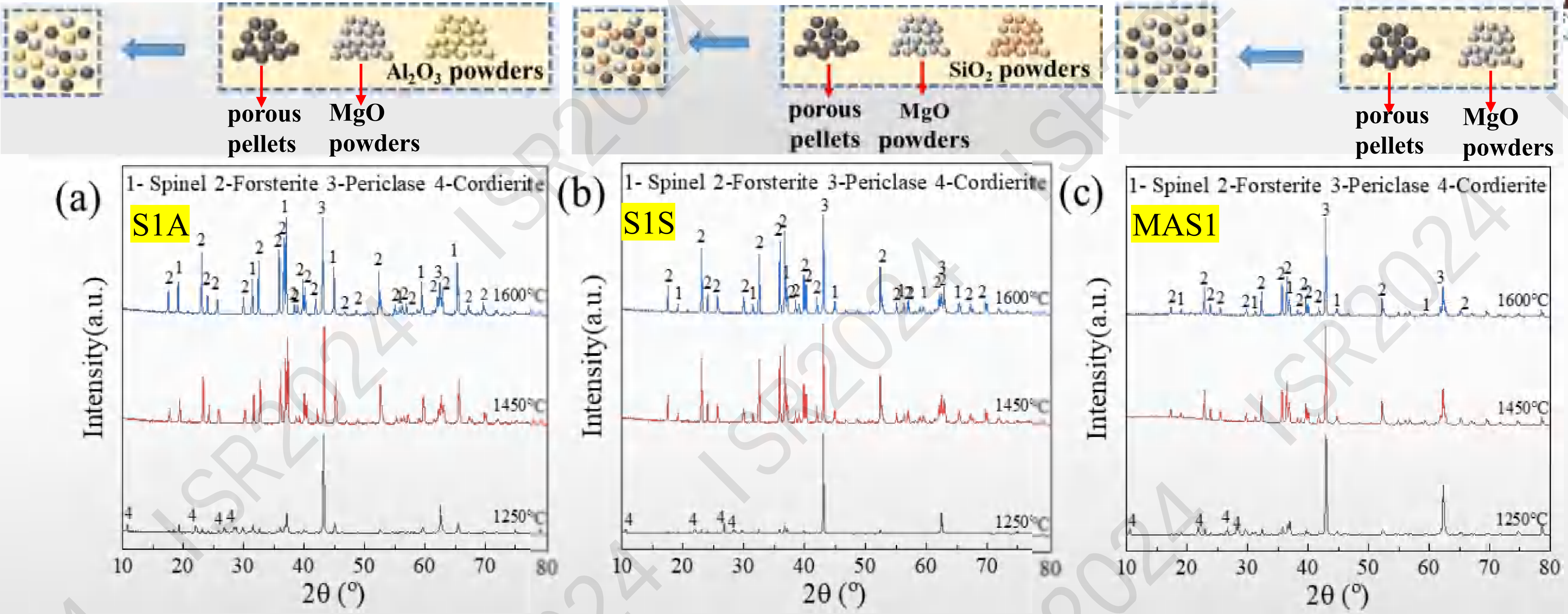


Fig. 7 XRD patterns of samples after sintering at 1250-1600 °C: (a) S1A and (b) S1S (c) MAS1.

Liquid phase reaction:

$$Al_2O_3\ (l) +\ MgO\ (s) \rightarrow MgAl_2O_4\ (s) \qquad (1)$$

$$SiO_2\ (l) +\ MgO\ (s) \rightarrow Mg_2SiO_4\ (s) \qquad (2)$$

03 Experimental Results

Sintering behavior

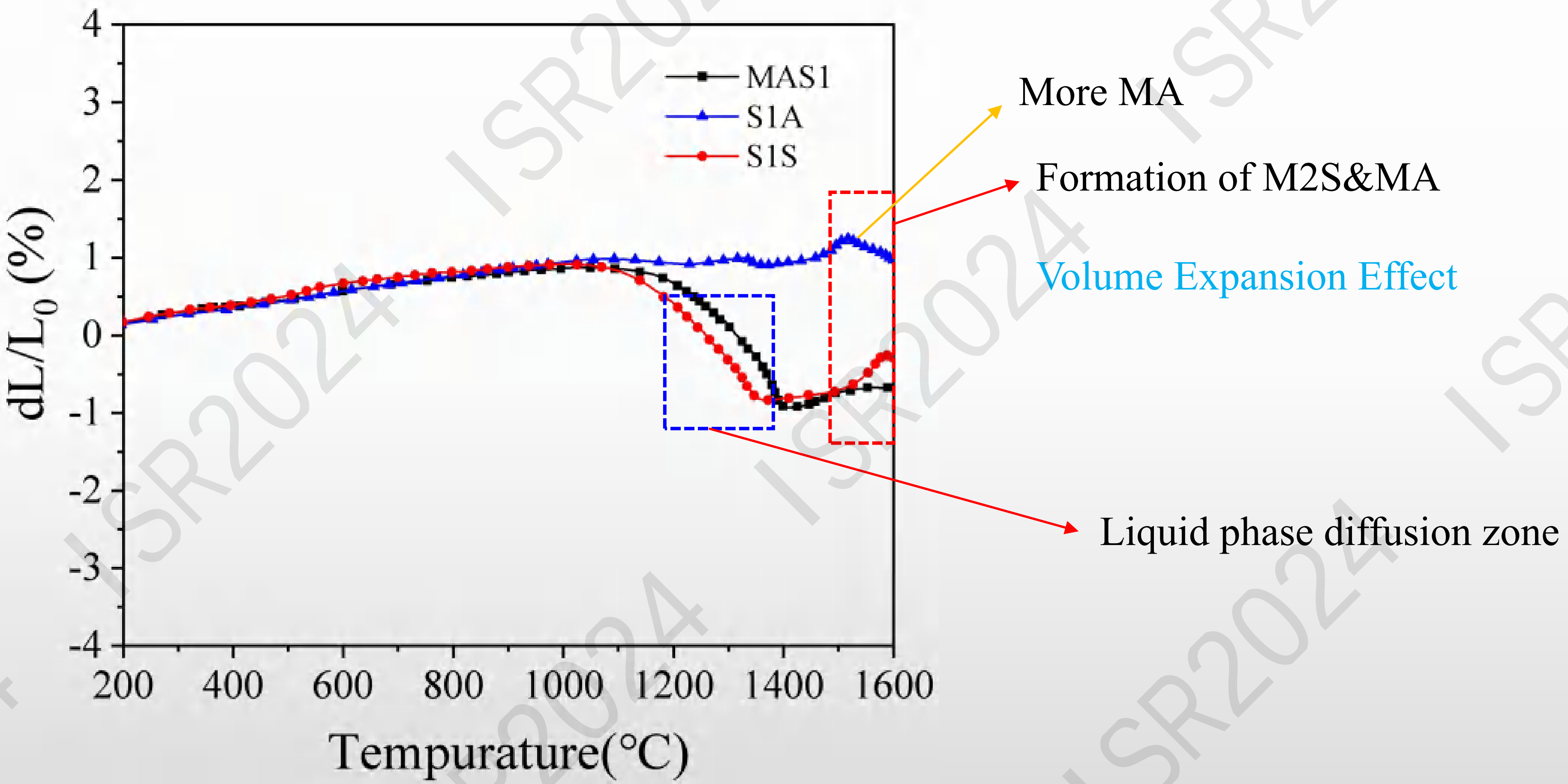


Fig. 8 Linear change of samples during heating at 200-1600 ^{o}C

03 Experimental Results

Microstructure Evolution

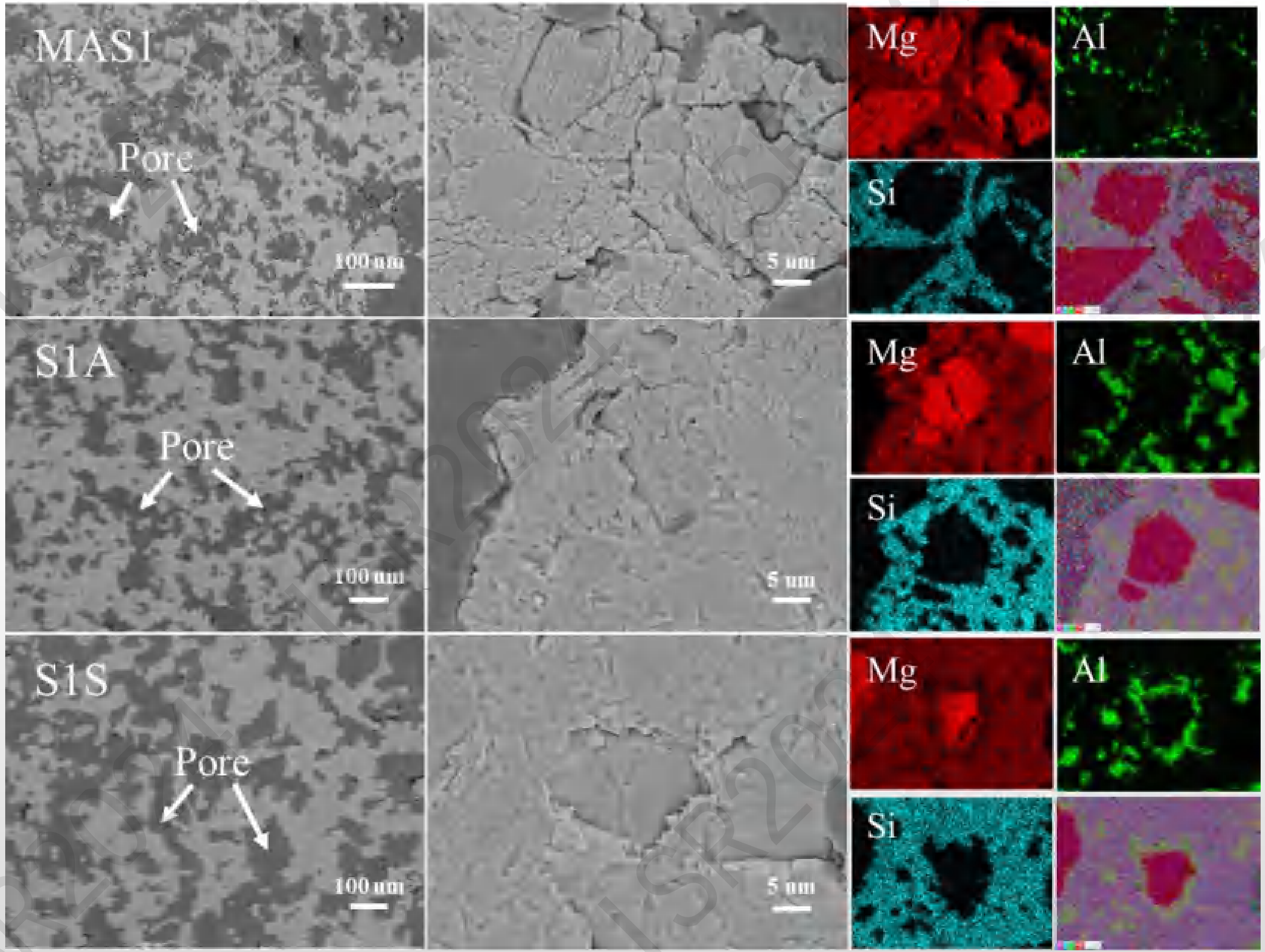
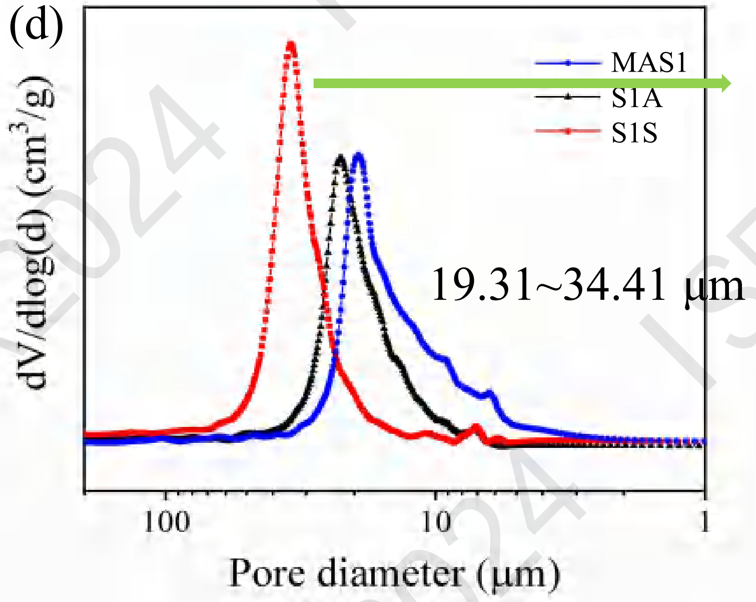


Figure. 9 Microstructure images and EDS mappings of MAS1, S1A and S1S samples sintered at 1600 °C

03 Experimental Results

Physics properties



More of the transitional liquid phase.

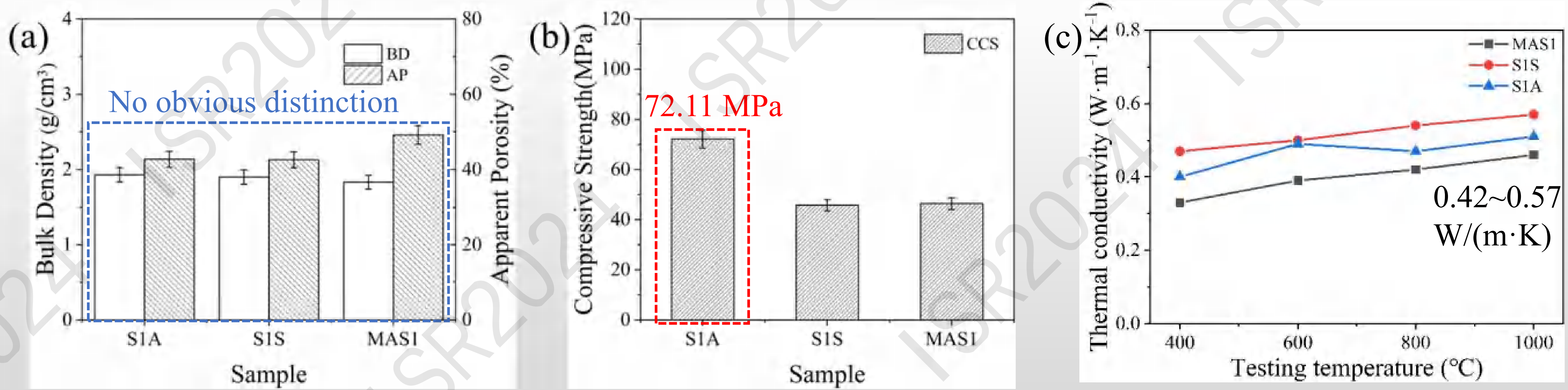


Fig. 10 Physical properties of MAS1, S1A and S1S samples after sintered at 1600 °C : (a) BD and AP, (b) CCS, (c) Thermal conductivity values, (d) Pore size distribution of S1A, S1S and MAS1 samples sintered at 1600 ° C

Physics properties

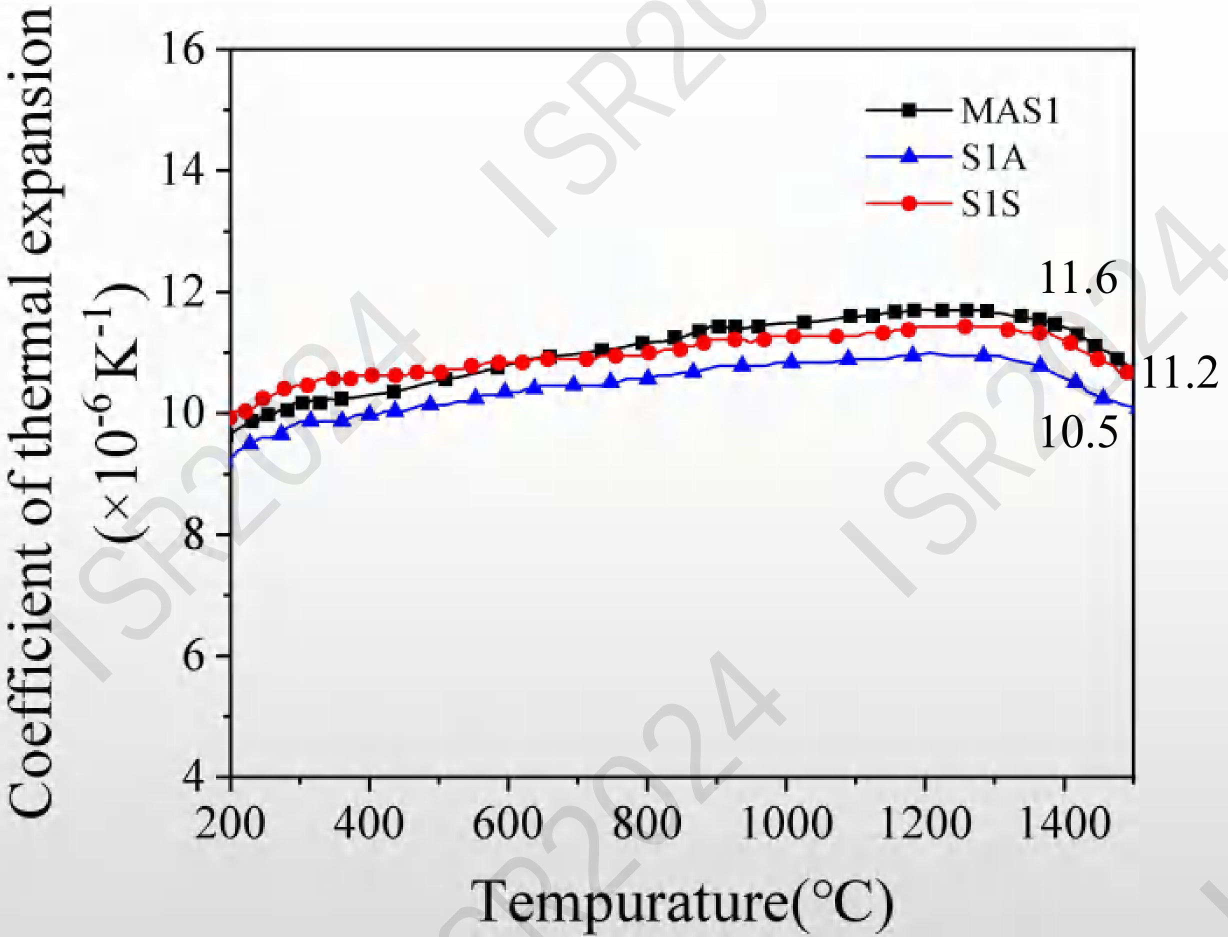


Fig. 11 Thermal expansion coefficient of samples sintered at 1600 °C.

Spinel: 7.6×10^{-6}/K；

Forsterite: 11.3×10^{-6} K^{-1}

Periclase: 13.5×10^{-6}/K

The thermal expansion coefficient of a composite material is related to the thermal expansion coefficients of its constituent components as well as the relative content of each crystal phase.

Physics properties

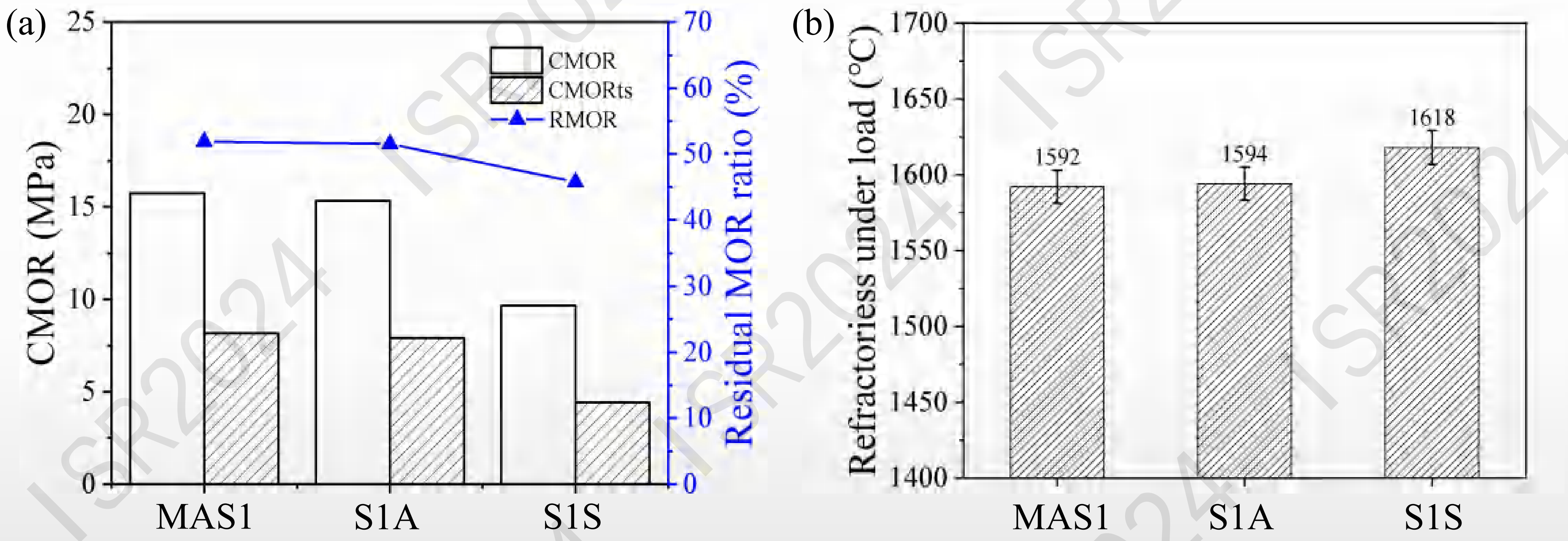


Fig. 12 (a) Thermal shock resistance of samples MAS1, S1A and S1S, (b)Refractoriness under load of MAS1, S1A and S1S samples sintered at 1600 °C.

1. Adding 13.5 wt% α-Al_2O_3 to the porous material increased magnesia-alumina spinel content after calcination, enhancing its room temperature compressive strength to 72.11 MPa, with a volume density of 1.90 g/cm3 and porosity of 42.8%.

2. Incorporating 8 wt% silica increased forsterite content to 75 wt%, forming a skeleton structure that improved high-temperature properties. The composite material has a volume density of 1.93 g/cm3, porosity of 42.6%, and a load softening temperature of 1618 °C.

3. The S1S sample with a higher forsterite content and larger grain size forms a skeletal structure, enhancing the material's load softening temperature, demonstrating the potential to improve refractory properties through phase and pore structure adjustments.

Thanks for listening.