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University of Science and Technology Liaoning

Thermal stress analysis of ladle refractory under coupled temperature and stress fields based on ANSYS software

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CONTENT

1.1 Introduction of ladle

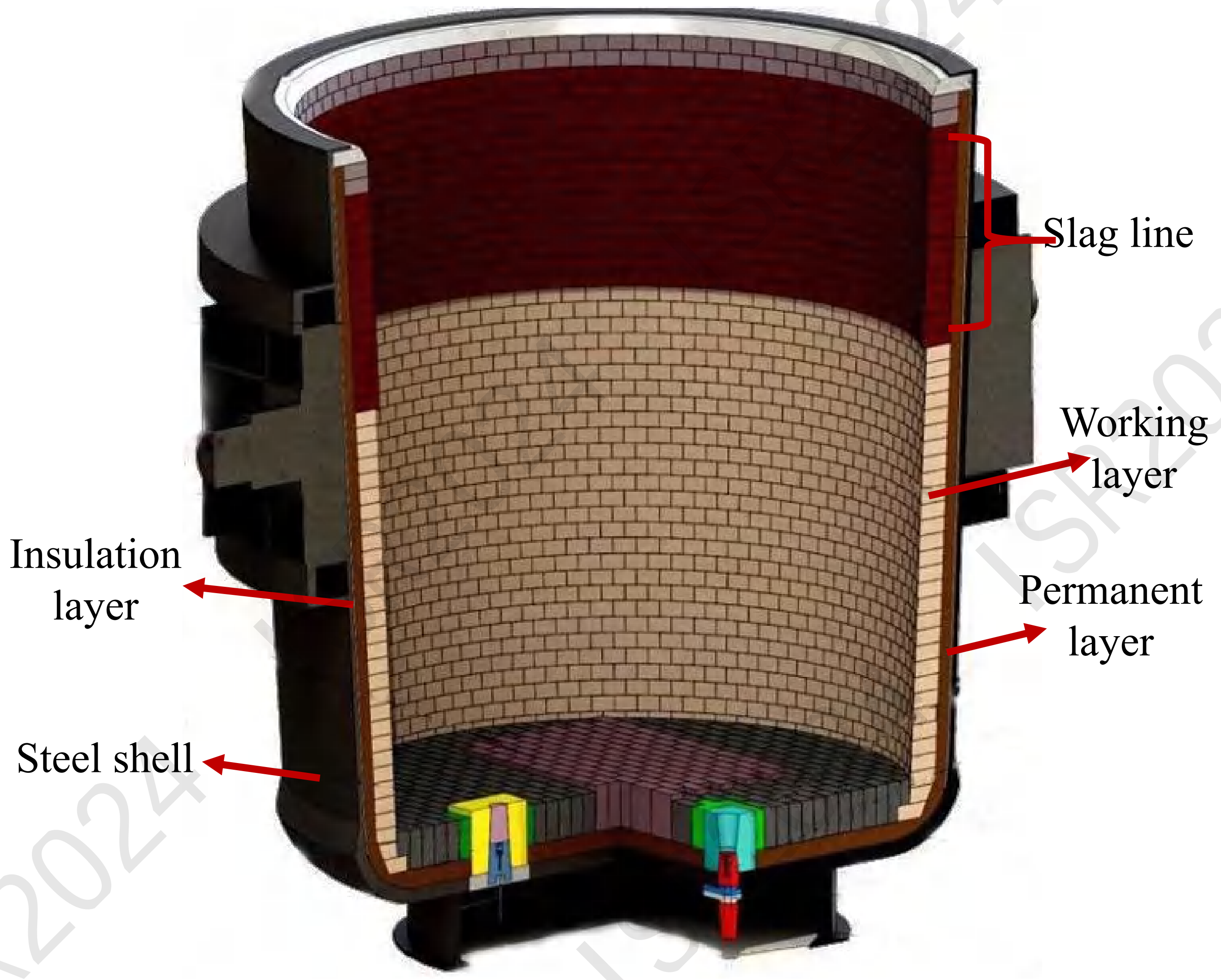


Fig.1 Diagram of the ladle structure

Steel ladle is an important equipment in steelmaking, which has the multi-functional roles of liquid steel heat preservation, container transportation, temporary smelting and so on .

1.2 Purpose and significance of the study

Temperature difference → Thermal stress

Erosion of steel slag and molten steel

Damage to ladle linings

In the actual production process, there is no relevant equipment to measure the thermal stress of the ladle.
In order to predict and lengthen the ladle life, I use the ANSYS software to simulate and calculate the temperature distribution and thermal stress distribution in the ladle lining.
I am able to find the location of the maximum thermal stress in the ladle by simulating, Then we adjust the refractory configuration.

2.1 Research idea

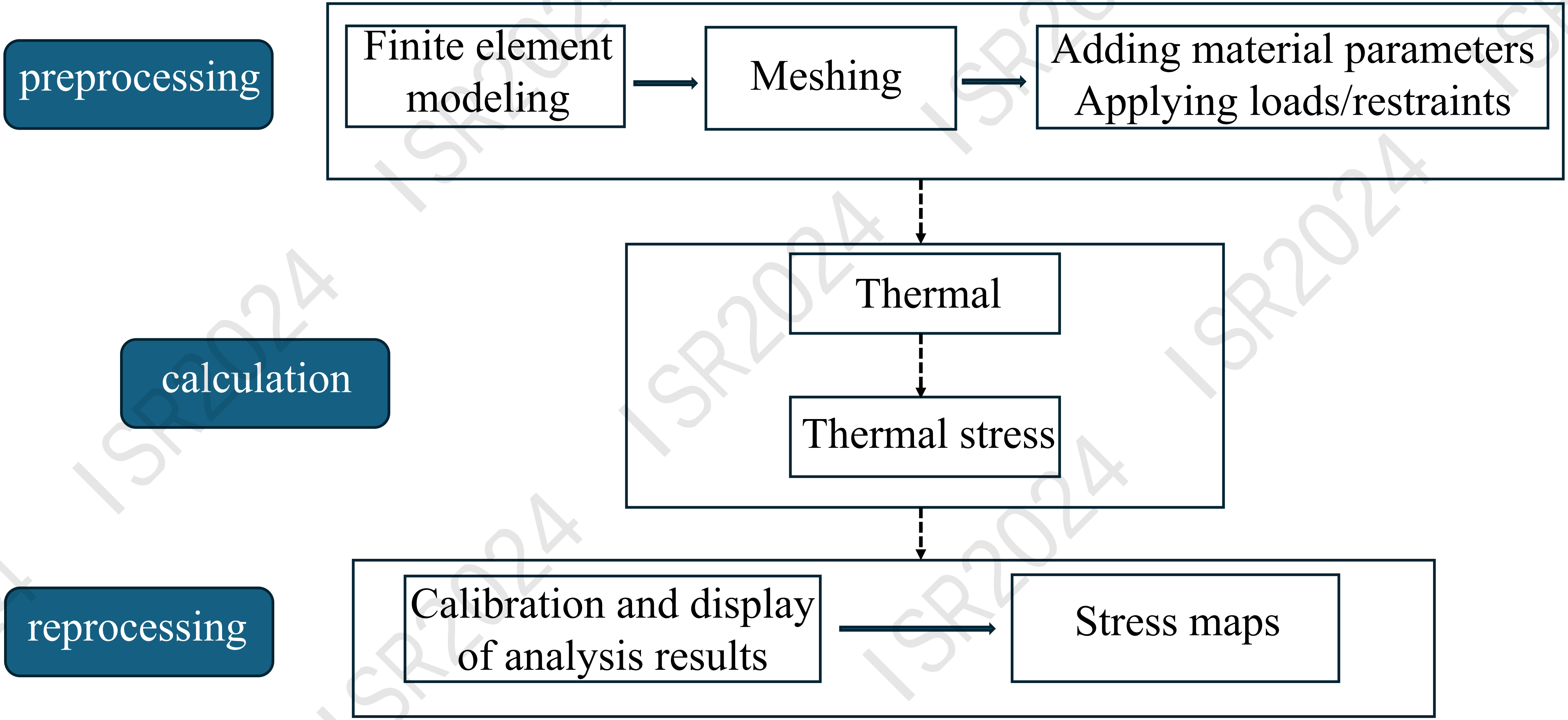


Fig.2 Flowchart of research idea

2.1 Research idea

(1) Finite element modeling

①Due to the small inclination of the actual ladle wall to the bottom of the ladle, the model of the ladle is simplified to a cylinder.

②Neglecting the effects of permeable turns at the bottom of the ladle, sliding spouts and drives.

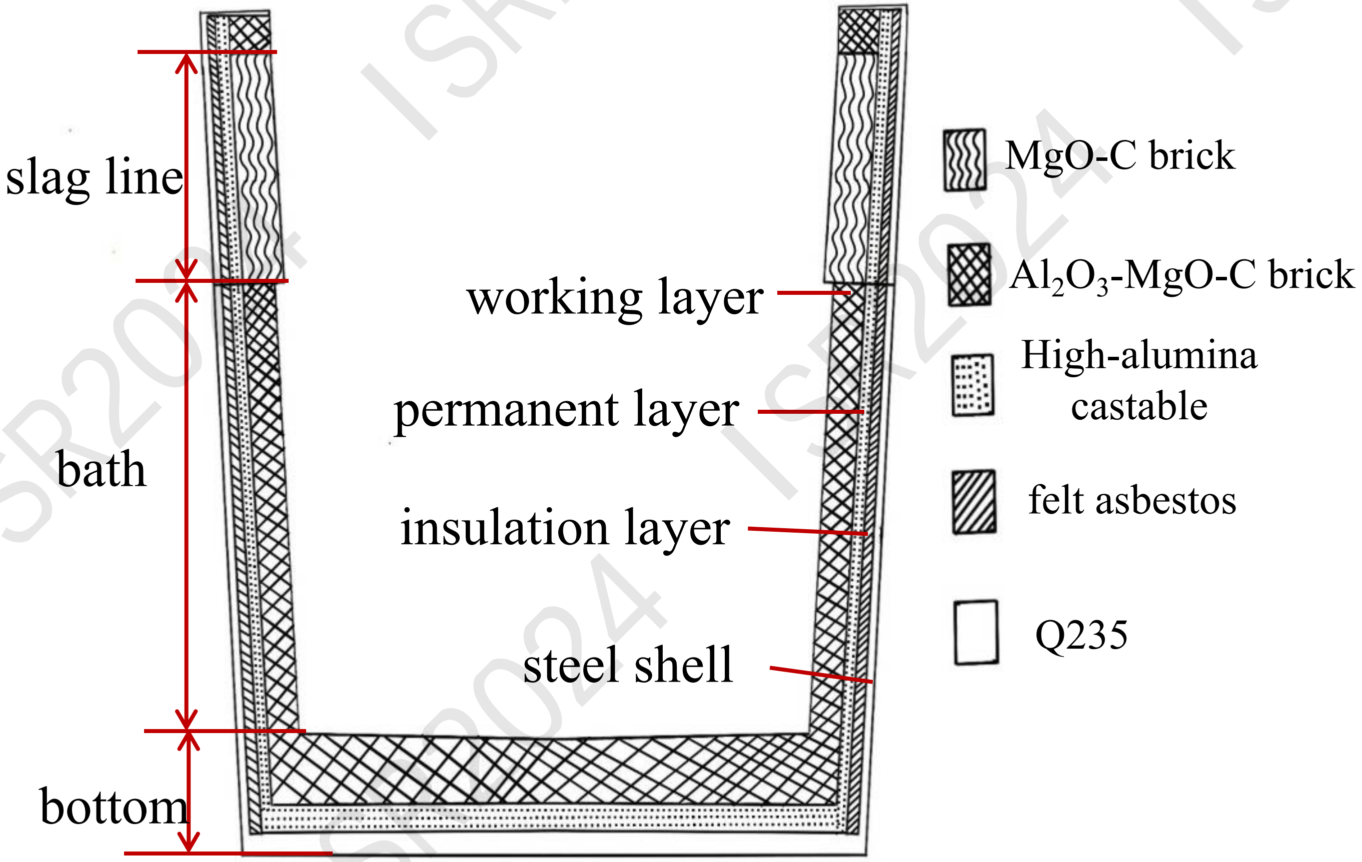


Fig.3 Diagram of structure of ladle lining materials

2.1 Research idea

(2) Meshing

①Using hexahedral meshing
②Setting the 100mm cell size

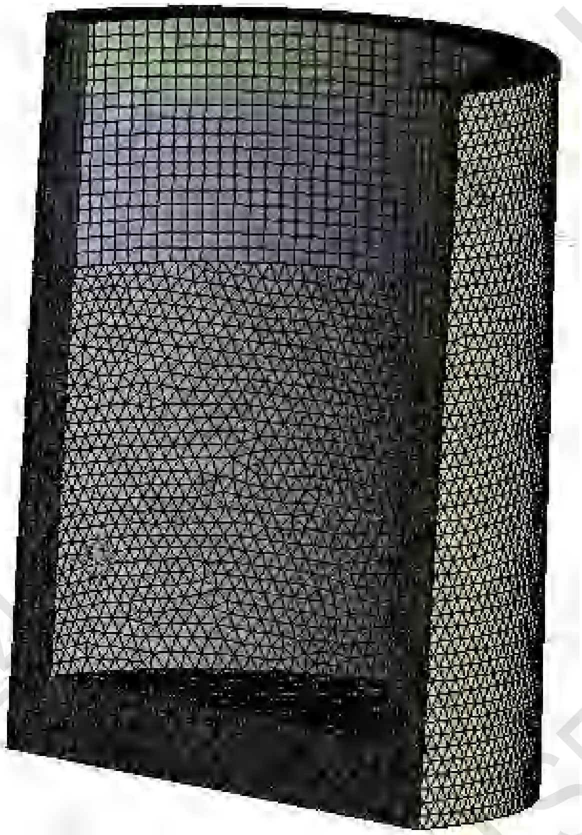


Fig.4 Meshing diagram of the ladle

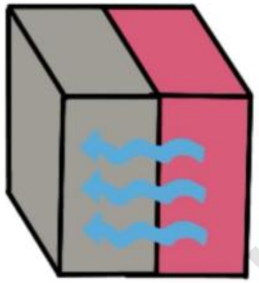
(3) Material parameters adding

Table 1 Physical parameters of refractory materials for ladle linings

	temperature ℃	MgO-C brick	Al_2O_3-MgO-C brick	High-alumina castable	felt asbestos	steel shell
density/kg·m^{-3}	ordinary temperatures	3100	2950	2800	1150	7850
thermal conductivity W·（m·K）$^{-1}$	<1000	13.6	3	0.713	0.126	34
	≥1000	12.0	3	0.713	0.126	31
specific heat J·（Kg·K）$^{-1}$	<1000	960	800	900	815	460
	≥1000	960	1200	1500	815	460
thermal coefficient of expansion（×10^{-6}）	ordinary temperatures	10.2	5	5.8	1.2	13.7
elasticity modulus /MPa	ordinary temperatures	10200	6300	5700	2000	206000
Poisson's ratio	ordinary temperatures	0.21	0.21	0.21	0.01	0.3

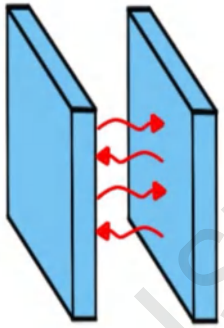
2.2 Calculation Method

Heat transfer method



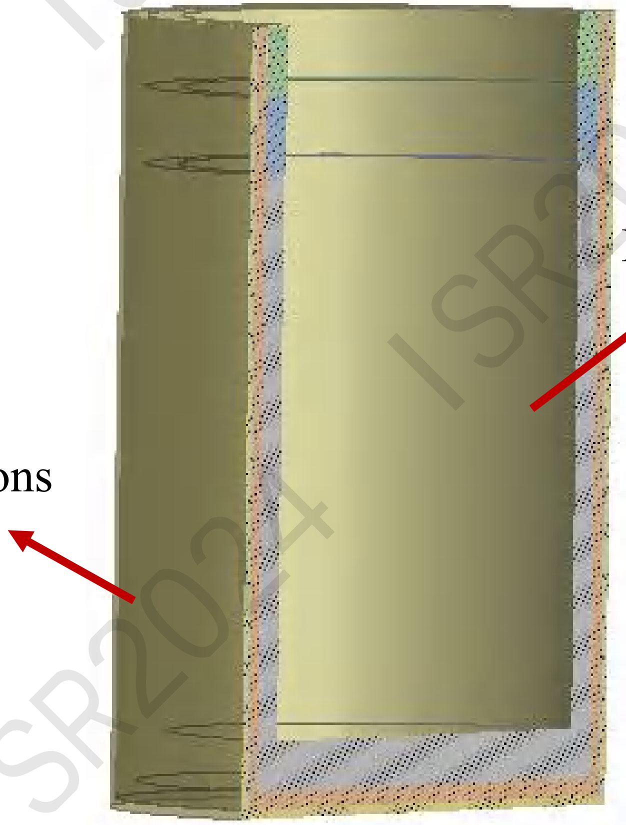
heat conduction

heat convection



heat radiation

Boundary conditions



3.1 Temperature field analysis

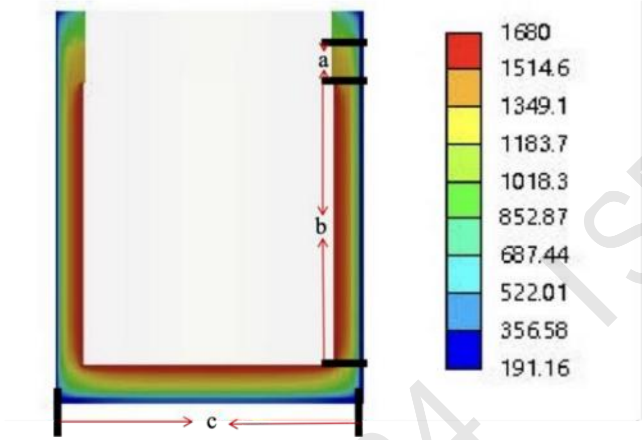


Fig.5 Cloud diagram of the temperature distribution of the ladle overall

Fig.6 Cloud diagram of the temperature distribution in the slag line

the temperature at the bottom of the steel shell is higher than that at the wall of the steel shell.

Fig.7 Cloud diagram of the temperature distribution in the bath

Fig.8 Cloud diagram of the temperature distribution at the bottom the ladle

3.1 Temperature field analysis

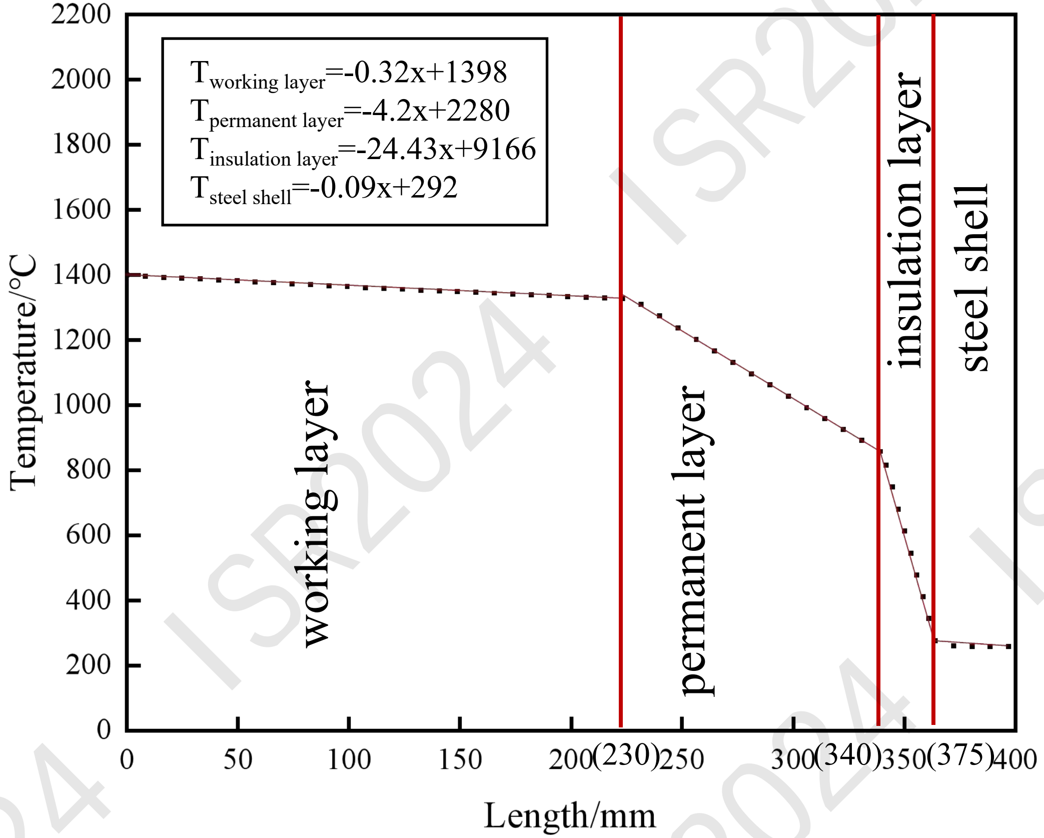


Fig.9 Temperature variation diagram of slag line

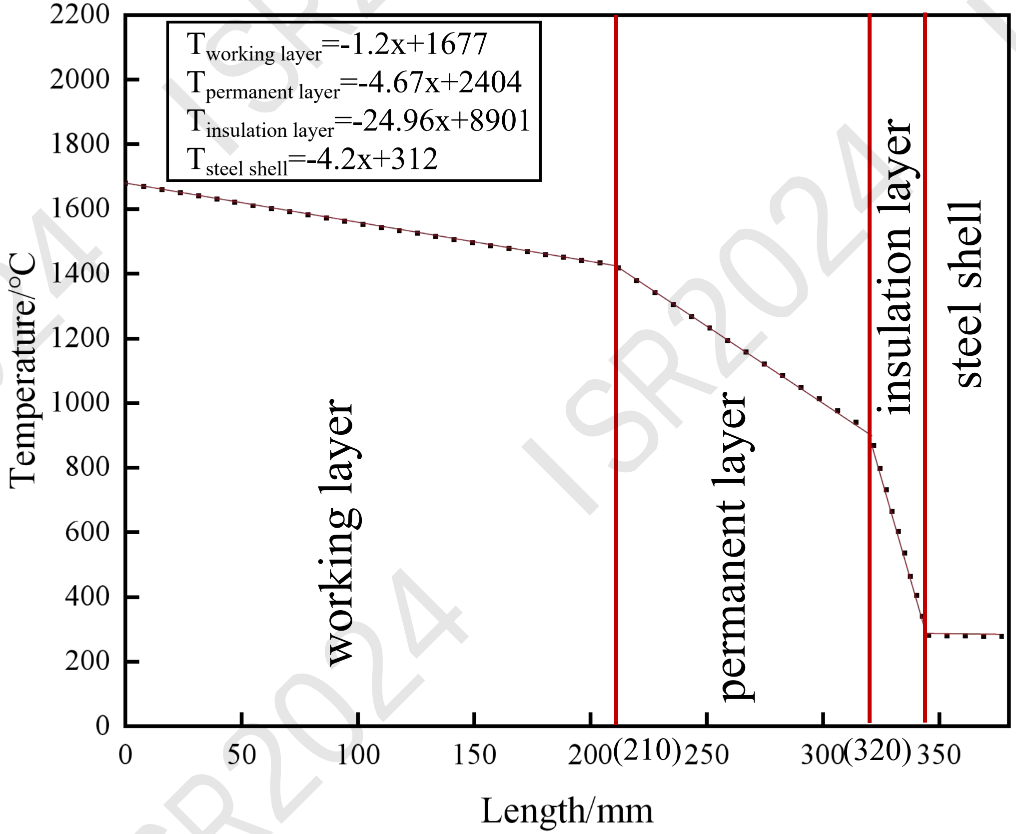


Fig.10 Temperature variation diagram of the bath

3.1 Temperature field analysis

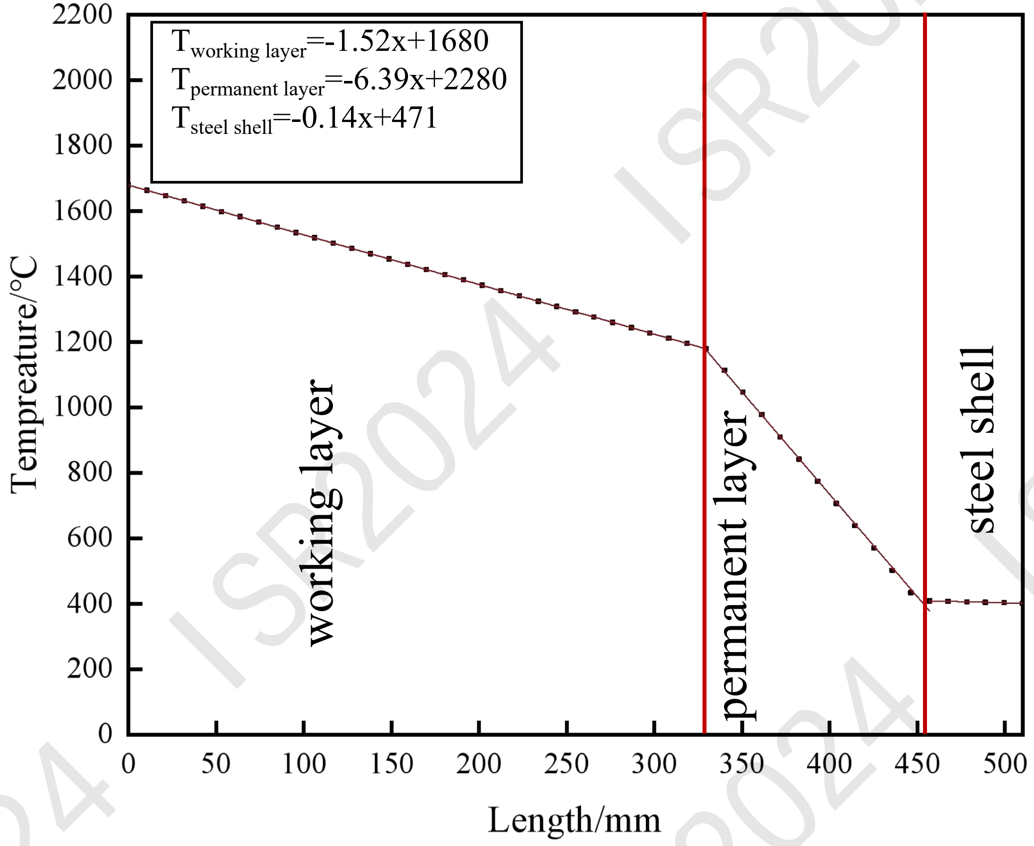


Fig.11 Temperature variation diagram at the bottom of the ladle

Temperature at different locations in the linings of the three regions varied linearly with distance from the working face.

3.2 Thermal Stress Analysis

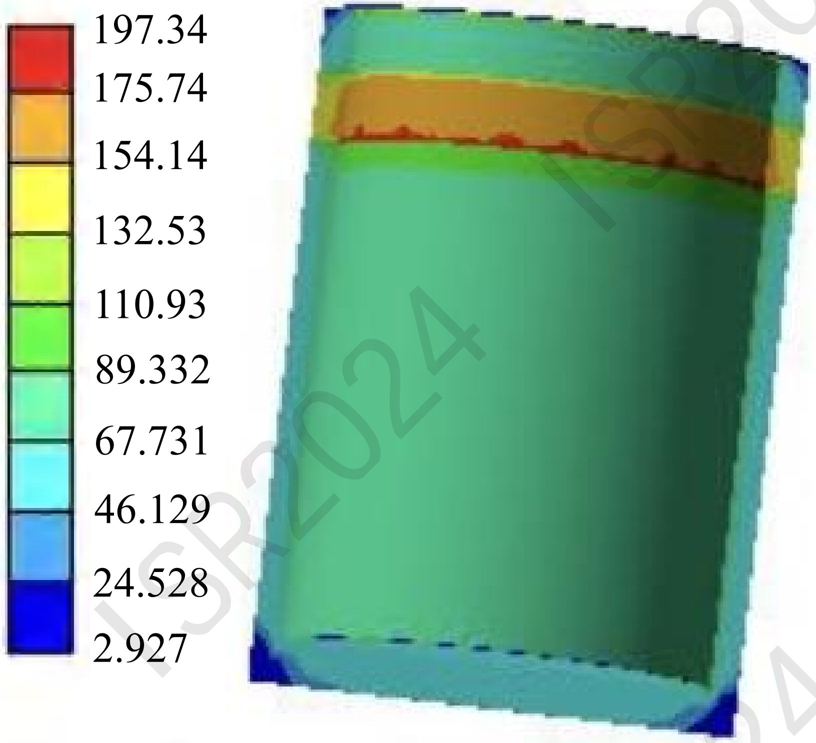


Fig.12 Cloud map of thermal stress distribution in the working layer

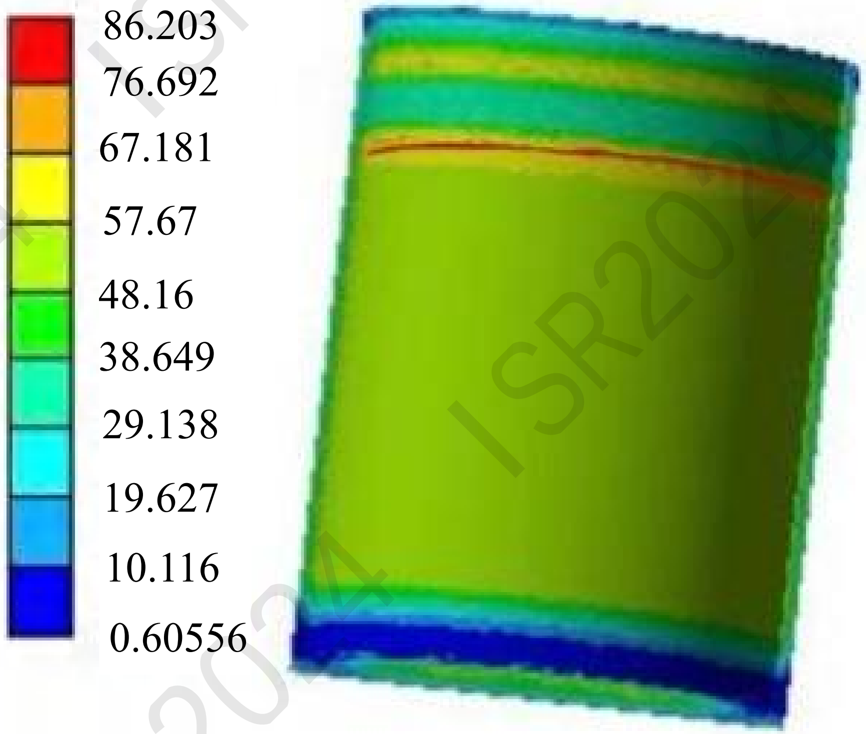


Fig.13 Cloud map of thermal stress distribution in the permanent layer

3.2 Thermal Stress Analysis

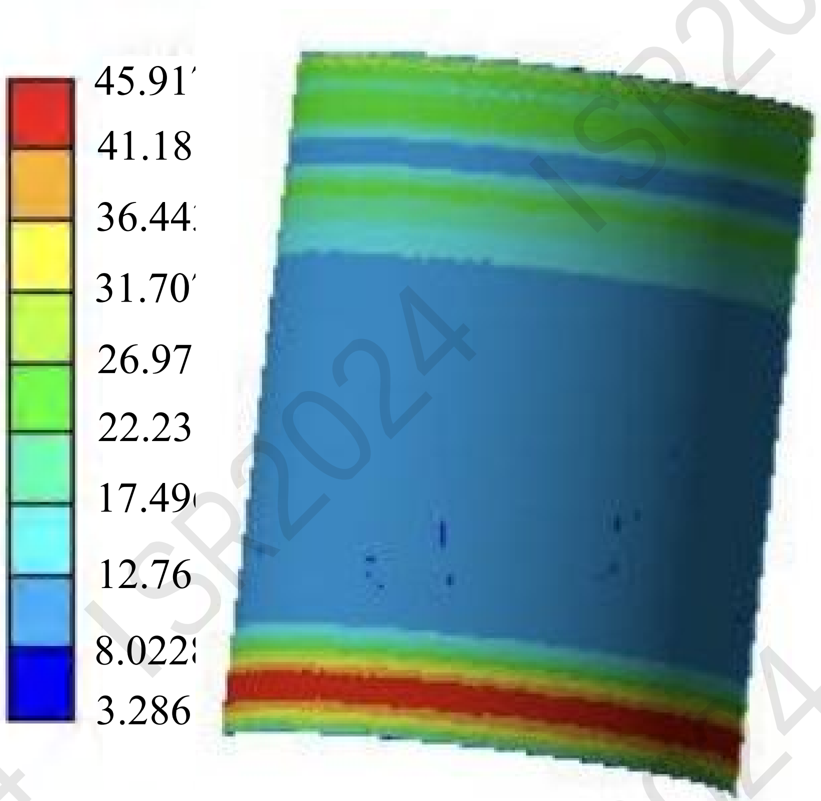


Fig.14 Cloud map of thermal stress distribution in the insulation layer

Maximum thermal stress in the working layer is at the slag line；
The maximum thermal stress in the permanent layer is behind working layer of slag line;
The maximum thermal stress of the insulation layer is at bottom of the insulation layer.

3.3 Microstructure analysis

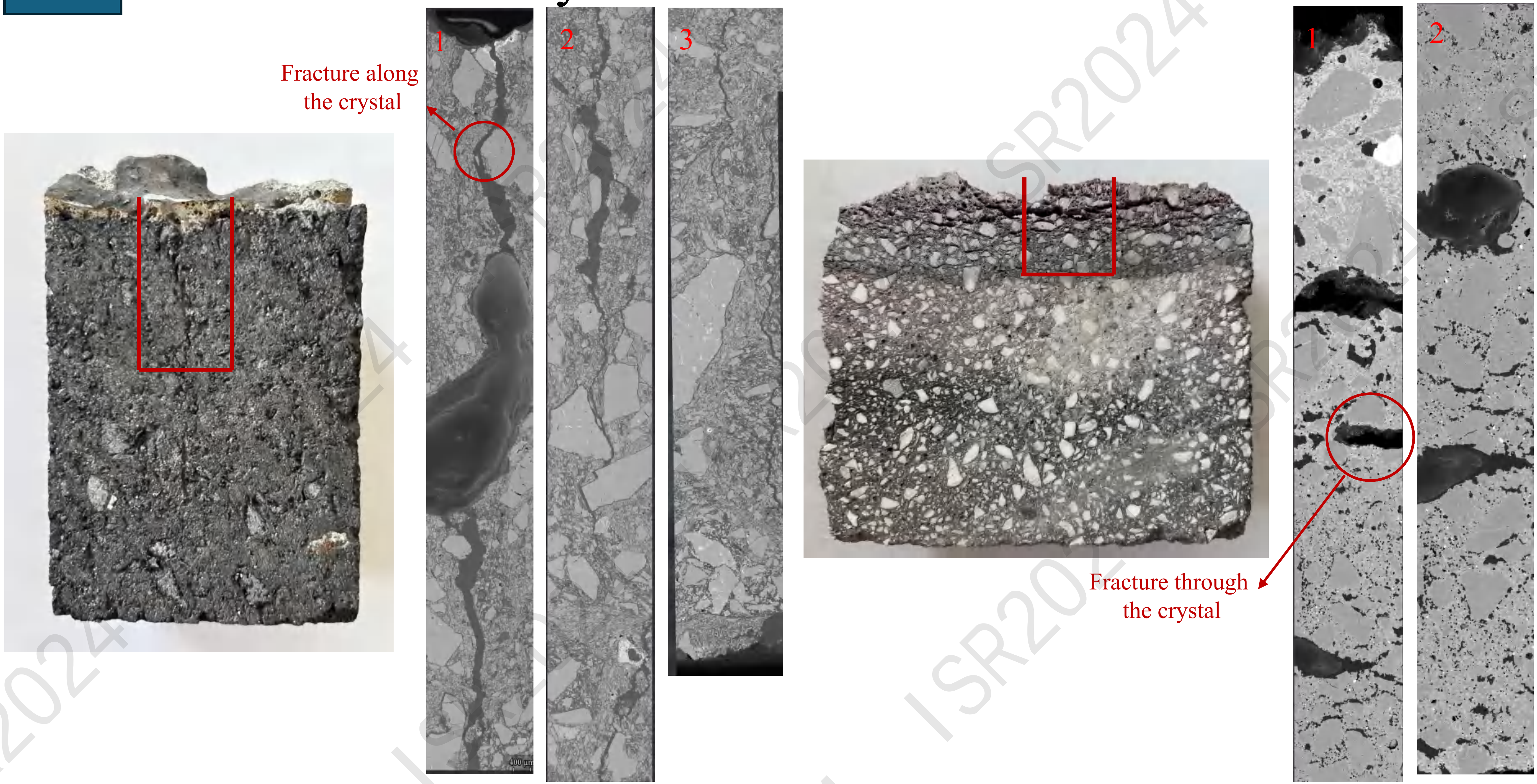


Fig.15 Macrostructure and microstructure graphs of bricks used in the slag line and the bath

3.3 Microstructure analysis

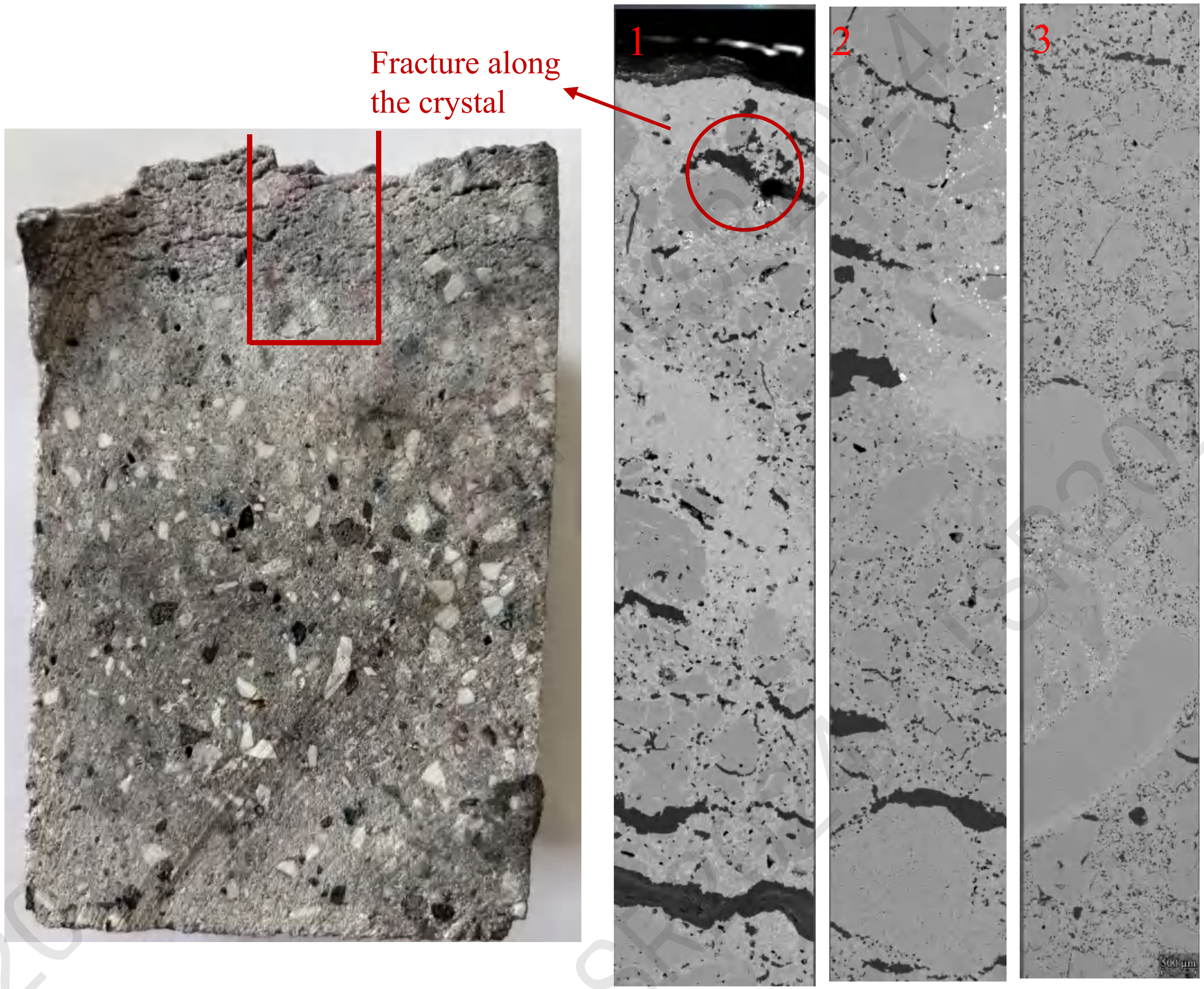


Fig.16 Macrostructure and microstructure graphs of bricks used at the bottom of the ladle

There are crakes in the bricks used because of the thermal stress. And then according to the continuous microstructure diagrams, these can be seen that cracks are generated from the working surface to the non-working surface. In addition, they get smaller and smaller until disappear. Cracks suffer chemical attack first of matrix and then of filling agent.

These conclusions are consistent with the simulation results.

4 Conclusion

（1） The temperature in different regions is slightly different, the temperature at the bottom of the ladle is higher than that at the wall of the ladle. And the temperature of the ladle lining in the same material is linearly distributed. The temperature of each part of the ladle can be predicted according to the fitted linear equation.

（2） The maximum thermal stress of the ladle appears at the slag line and decreases with distance from the working face. And the slag line is subjected to the highest thermal stress, resulting in cracking the largest crack.

（3） In addition, the microstructure graphs are consistent with the simulation results. Furthermore, we can optimize the areas of most damaged based on the simulation results, strengthening its resistance to compression and erosion.

thank you for listening！

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