

A new oolitic content test method for green sand by repeated approximation

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Abstract: The reuse of green sand in casting production is hindered by the accumulation of oolitic deposits, primarily composed of clay binder with surface degradation, which may adversely affect the the moulding sand performance. Currently, there is a lack of standardized methods for quantifying the oolitic content. Accurate measurement of oolitic content is of great significance to the reuse of green sand. Attempts to determine oolitic content using potassium hydroxide (KOH) and phosphoric acid (H₃PO₄) methods encounter challenges due to their excessive reactions with SiO₂ in the sand. In this study, an improved method for measuring the oolitic content of green sand with repeated approximations was proposed. This method judges the chemical activity of the sample surface through the change of its mass to accurately obtain the mass of the reaction oolitic deposits. The test result of the used sand samples from the foundry shows that the oolitic deposits are completely removed after reacting with KOH solution three times at 300 °C for 20 min. SEM and EDS also show that after three times of reactions, the surface of green sand becomes smooth and the content of Al-containing oolitic deposits is very low. This indicates that the method can accurately control the extent of the reaction. Implementation of this method at Huangshi Dongbei Casting Co., Ltd. has yielded consistent and reliable test results, effectively mirroring variations in green sand oolitic content on the production line. This new method is expected to be widely adopted to improve the efficiency and quality of reused green sand in casting operations.

Keywords: green sand; oolitic content; repeated approximation; reuse of green sand

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1 Introduction

Due to its low cost of raw materials, easy treatment, strong reusability, and strong ability to adapt to molding conditions, the green sand is currently the most widely used casting sand^[1-2]. The green sand is made of bentonite, silica sand, water, and other additives such as coal or starch^[3]. Bentonite, as a binder, is a non-metallic mineral with montmorillonite as the main mineral component. Its main chemical components are SiO₂, Al₂O₃, and H₂O, as well as Fe, Mg, Ca, Na, K, and other elements^[4-8]. Bentonite expands when absorbing water, disperses and covers the surface of sand particles to form a viscous film after sand mixing. This film

gathers the sand particles together through a hydrogen bond to make the mold obtain enough strength and maintain the required shape during molding process and metal pouring^[9-11].

The recycling performance of bentonite is significantly affected by the mold's temperature field during pouring^[12]. When the temperature is below 300 °C, bentonite will only lose free water and can be completely recycled^[13]. Schiebel et al.^[14] made the green sand undergo 22 times of drying and rewetting cycles below 225 °C, and its water absorption performance and tensile strength did not change significantly. At above 300 °C, the binding ability of bentonite was gradually losing. At 500 °C to 700 °C, montmorillonite undergone a dehydroxylation reaction. Holtzer et al.^[15] observed that a bentonite could undergo two endothermic dehydration processes at 519 °C and 672 °C, respectively. When the bentonite was heated to 600 °C, the montmorillonite content gradually decreased. After the bentonite was kept at 700 °C for

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1 h, the montmorillonite content was almost zero, and the bentonite lost binding property. When the temperature reached above 700 °C, Khan et al.^[16] believed that the dead clay, which had lost its cohesive ability would be sintered in large quantities. The sintered dead clay closely combined with the sand particles to form the oolitic deposits, which were difficult to remove. When the temperature was higher than 900 °C, the phase structure of montmorillonite was completely destroyed and transformed into amorphous phase. At 1,100 °C, the amorphous phase was recrystallized to form a new cristobalite phase^[17].

The recovery and reuse of foundry green sand has great environmental and economic value. However, in the recycled green sand, the bentonite layer deactivated by high temperature will adhere tightly to the surface of the sand grains and form oolitic deposits during multiple accumulations. It may influence the properties of moulding sand and the quality of casting. Hofmann et al.^[18] proposed that the oolitic process increased the particle size and the roundness of the related sand. It is pointed out that moderate oolitization is conducive to reducing thermal expansion and avoiding sand expansion defects. However, when the oolitic content is too high, due to the insufficient fire resistance of the thicker wrapped oolitic deposits, the sand mold will be penetrated or even burned through, resulting in rough casting surface and serious sand sticking^[19]. However, at present, there is no uniform methods for the determination of oolitic content. In the existing chemical testing method, concentrated H_3PO_4 or KOH is used to remove the oolitic deposits. But at the same time, it will also react with silicon dioxide and cause excessive corrosion. Thus, the error is too large and the repeatability is poor. Therefore, it is necessary to develop an accurate oolitic content test method to explore the impact of oolitic content on the properties of molding sand and facilitate high-quality recycling of molding sand in the foundries.

In this study, a new method for measuring the oolitic content

of green sand with repeated approximations was proposed. It included pretreatment operation, blank control group design, repeated reactions, and calculation of oolitic content. The surface state of sand particles under different reaction times was characterized by SEM and EDS, which proved that repeated reactions can control the extent of reaction of the oolitic deposits, and the sample with complete reaction was obtained. This study is helpful to the quality control of molding sand in the foundries, and has great practical value and application prospects.

2 Experimental procedure

2.1 Pretreatment method

The components of green sand on the production line are complex. In addition to sand particles and closely combined oolitic deposits, there are loosely combined dead clay, active clay, residual pulverized coal additives, residual resin in mixed cores sand, etc. Therefore, to test the oolitic content, the impurities in the reclaimed green sand should be removed through pretreatment (water washing, burning, and pickling). The pretreatment steps and the changes in sands morphology are shown in Fig. 1.

The first step of pretreatment was water washing. Sufficient water was used to wash the wet sand sample until the turbid solution became clear to remove water soluble impurities and mud. The sample was still black at this time, indicating that there was still residual pulverized coal adhering to the sand surface.

The second step of pretreatment was burning. The sample was heated at 900 °C and held for 1 h to volatilize and remove residual organic compounds such as pulverized coal. After burning, the whole sample was red in color.

The third step of pretreatment was pickling. Totally, 200 mL $6\text{ mol}\cdot\text{L}^{-1}$ hydrochloric acid solution was added to the sample after burning in the second step. Heated the sample to 300 °C



Fig. 1: Pretreatment steps and changes in sands morphology

and held for 30 min to remove the metal particles penetrating the molding sand during pouring. At this time, the sample showed the original color of the sand particles, and the impurities in the used sand were fully removed.

2.2 Potassium hydroxide method and the phosphoric acid method

Both potassium hydroxide^[20-22] and phosphoric acid^[16, 23, 24] can react with the oolitic deposits to remove it. The proportion of sample mass reduction before and after the reaction equals the oolitic content. In this study, the corresponding methods were called the potassium hydroxide method (KOH method) and the phosphoric acid method (H_3PO_4 method), and further research was conducted.

The procedure of the potassium hydroxide method is as follows: 24 g KOH, 100 mL distilled water, and 20 g of pretreated used sand sample were added into the beaker. Then, heated the solution to 400 °C and kept for 20 min. After the reaction completed, cleaned the sample with distilled water, then dried and weighed the remaining sand particles.

The procedure of the phosphoric acid method is as follows: 20 g pretreated used sand sample and 200 mL analytical pure H_3PO_4 with mass fraction of 85% was put into a beaker. The beaker was heated to 400 °C with a thermostatic heating plate and held for 1 h. The sample solution was cooled for more than

15 min, and then, the sample was cleaned, dried, and weighed.

Based on the recommended reaction temperature of 400 °C for the KOH method and H_3PO_4 method, the reactions of KOH [Fig. 2(a)] and H_3PO_4 [Fig. 2(b)] with both used sand containing oolitic deposits and new sand without oolitic deposits were investigated at different temperatures. Ideally, neither KOH nor H_3PO_4 should react with the new sand. However, in practice, at 400 °C, the reaction proportions of KOH and H_3PO_4 with new sand are 3.7% and 15.5%, respectively, indicating that both KOH and concentrated H_3PO_4 exhibit significant corrosion effects on silica sand, indicating the reaction between hot concentrated H_3PO_4 and SiO_2 being particularly strong. In the case of KOH, it removed approximately 5.5% of the oolitic deposits in the used sand at 300 °C. As the temperature rose to 400 °C, the reduction in mass increased significantly, suggesting an incomplete reaction at 300 °C. Notably, the reaction extent of KOH with used sand was consistently more pronounced than with new sand, indicating that the reactivity of KOH with the oolitic deposits is significantly higher than that with SiO_2 , allowing for preferential removal of the oolitic deposits through the KOH method. For H_3PO_4 method, minimal reaction occurred with either used or new sand at 300 °C. In contrast, substantial reactions occurred at 400 °C with both, making it difficult to control the reaction of H_3PO_4 solely with the oolitic deposits and not with SiO_2 .

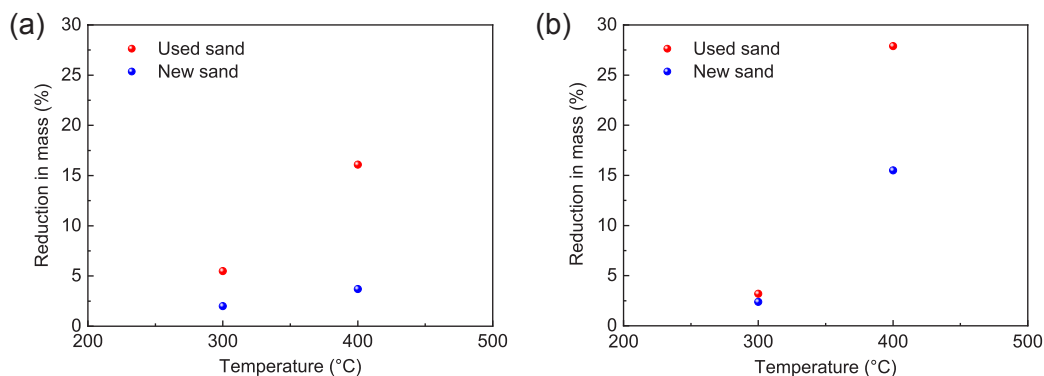


Fig. 2: Mass reduction of green sand after reaction with KOH (a) and H_3PO_4 (b)

The principle of KOH and H_3PO_4 reaction is not the same. KOH chemically reacts with silicon dioxide, the chemical reaction equation is $SiO_2 + KOH = K_2SiO_3 + H_2O$. This is a reaction between a strong base and a weak acid. The reaction mechanism of concentrated H_3PO_4 and silicon dioxide is entropy reduction. The reaction can only be carried out when P_2O_5 or polyphosphoric acid (PPA) is more volatile than SiO_2 . Under the condition of heating, silicic acid and H_3PO_4 can lose water together to form heteropoly acid. Therefore, the concentrated hot phosphoric acid can not only decompose most of the minerals, such as chromite, rutile, ilmenite, etc., but also corrode silica.

It can be seen that both the potassium hydroxide method and phosphoric acid method have an insurmountable huge problem. That is, a single reaction cannot ensure that the oolitic deposits are completely removed, while SiO_2 is not

removed. Concentrated phosphoric acid is highly corrosive to oolitic deposits and sand, and there is no obvious priority in its reaction with them. Thus, it is easy to overreact. The reaction of the potassium hydroxide method is insufficient to remove the oolitic deposits at 300 °C for 20 min. Otherwise, the new sand will also be corroded if the reaction conditions are strengthened. Therefore, a single reaction can not remove the oolitic deposits without corroding the new sand, nor can it accurately measure the oolitic content.

2.3 Potassium hydroxide repeated approximation method

Taking advantage of the fact that KOH can remove the oolitic deposits preferentially, a potassium hydroxide repeated approximation method (hereafter referred to as the new method) has been proposed by optimizing the KOH method.

The procedure of the new method is as follows: Before testing the used sand sample, 20 g of pre-treated new sand was used and the same procedure below as a blank control was followed. The reduced mass in the reaction was recorded as ΔM . This is to determine the corrosion ability of KOH to new sand under experimental conditions. When testing the oolitic content of the sample, 20 g sample (recorded as M_0) was put into a beaker, and 24 g of KOH and 100 mL distilled water were added. Then, the solution was heated to 300 °C and held for 20 min. After washing, drying, and weighing, the mass difference between the sample and the residual sand was recorded as M_1 . The above steps were repeated with the residual sand to obtain the mass of $M_2, M_3, M_4, \dots, M_n$. When $M_{n-1} - M_n \leq 1.1\Delta M$, it is considered that M_{n-1} has completely reacted. The oolitic content (OC) was calculated using the following equation. In general, $\Delta M < 0.5$ g, $n < 6$.

$$OC = \frac{M_0 - M_{n-1}}{M_0} \times 100\% \quad (1)$$

where: M_0 —the mass of tested sample, g; M_{n-1} —the mass of sand particles after drying after $n-1$ times of reaction, g.

In the potassium hydroxide repeated approximation method, the extent of reaction was controlled by the change of chemical reaction activity of the sample to make the reaction appropriate and achieve the goal of removing the oolitic deposits.

By conducting a small amount of chemical reaction with KOH solution, the oolitic deposits on the surface of the sand can be gradually removed. The reactivity of KOH with oolitic deposits is higher than that with SiO_2 . Therefore, as the oolitic deposits are gradually removed, the reaction activity of the sample decreases, and the amount of sample mass reduction after each reaction also gradually decreases. Based on this, the mass reduction of clean new sand before and after one treatment under the same conditions is taken as the blank control benchmark. When the mass difference of the residual sand particles after the last two treatments is close to or the same as the reduction amount of the blank reference, it means that the oolitic deposits on the surface of the reused green sand is close to or has been completely reacted. In this way, the oolitic content of recycled green sand surface can be accurately measured.

The molding sand materials used in this experiment were the new sand from Huangshi Dongbei Foundry Co., Ltd. (in Hubei, China, with a production of 130,000 t a year) and the green sand recycled from a cast iron production line. The reagents used in this experiment (potassium hydroxide and concentrated hydrochloric acid) were all analytical grade.

3 Results and discussion

3.1 Products by KOH method and H_3PO_4 method

The products formed by the reaction of H_3PO_4 and KOH with the sample at 400 °C were studied by XRD. The sample reacts with KOH to produce flocculent suspension, and the products

are separated from the remaining sand. The XRD pattern of the products is shown in Fig. 3(a). The products generated after the reaction include various mineral substances such as calcium aluminate sulphate, basic calcium silicate, xonotlite, nepheline, and poly calcium potassium gypsum. Potassium ions in KOH solution replace many sodium ions in the reaction process to form potassium calcium aluminum mixtures. This shows that the oolitic deposits are not a single component but a multiphase mixture. They react with KOH and precipitate various mineral precipitates. When the sample reacts with H_3PO_4 , black suspension will be produced. The XRD pattern of the products is shown in Fig. 3(b). It can be seen that, except for the SiO_2 , the products are all amorphous phosphates. This may be due to the viscous H_3PO_4 encapsulating and adsorbing on the sand surface. Under heating conditions, phosphate ions can corrode and destroy the crystal structure of the sand surface, peeling off the oolitic deposits and SiO_2 , floating with the flow of viscous liquid, and then forming amorphous phosphate products with dehydration process.

The XRD patterns of the sand before and after the reaction are shown in Fig. 3(c). Regardless of whether the oolitic deposits are removed or not, the sand sample is mainly composed of quartz, and the peaks of the oolitic deposits are covered. After reacting with KOH, the diffraction peaks at 36.5°, 39.5°, 40.3°, and 50.1° are significantly enhanced, corresponding to the (110), (102), (111), and (112) crystal planes of quartz, indicating that some high index crystal planes of SiO_2 are exposed during the reaction process.

The XRD results also indicate that the principles of removing the oolitic deposits by H_3PO_4 method and KOH method are different. KOH reacts with the oolitic deposits to form various alkaline silicates and oxides, which then crystallize and precipitate. The reaction between H_3PO_4 and the oolitic deposits will destroy the structure of the oolitic deposits, forming amorphous phosphate products that separate from the sand. The reaction between KOH and the oolitic deposits follows general chemical reaction kinetics. As the concentration of reactants decreases, the reaction rate decreases. Therefore, the amount of reaction can be used to determine whether the oolitic deposits has been removed.

The optical microscope images of the used sand samples after reaction with KOH or H_3PO_4 are presented in Fig. 4. The sand predominantly exhibits a grayish-white hue, interspersed with yellow and black grains. This may be due to the presence of other mineral impurities. Following the reaction with H_3PO_4 , the sand appears whiter and finer than that treated with KOH. This observation suggests that concentrated hot H_3PO_4 exhibits a strong etching effect on SiO_2 , leading to elevated test results from the H_3PO_4 method and introducing considerable experimental errors.

To test the corrosion effect of H_3PO_4 and KOH on silica sand, clean new sand was used as the sample. That is, the theoretical oolitic content of the sample is 0. However, the actual test results of KOH and H_3PO_4 reduced the mass of new sand by

3.7% and 15.5%, respectively (Fig. 2). The morphologies of the new sand before and after the reaction are shown in Fig. 5. Before reaction, although the mostly original sands are gray and white and transparent, it is also mixed with many particles of different colors, and the color of the surface is also relatively cloudy. This may be due to the absorption of various cations on the surface of the primary placer during its formation. After the

reaction with KOH, the surface of the new sand is consumed by the reaction, and the color of the sand becomes white. The sand reacted with H_3PO_4 goes even further and becomes almost uniformly white. All these indicate that KOH and H_3PO_4 have obvious corrosion effects on silica sand. Under the experimental conditions, the corrosion degree of KOH is less than that of concentrated H_3PO_4 .

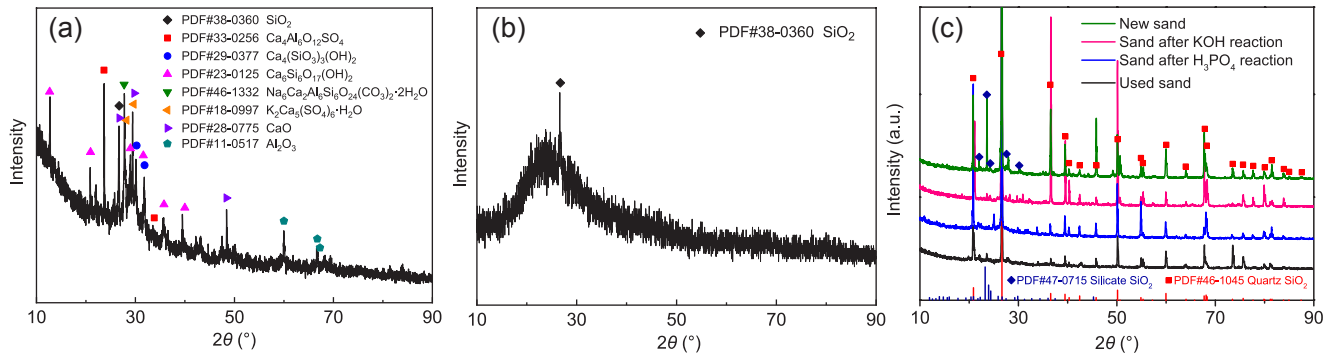


Fig. 3: XRD results of reaction products of oolitic deposits with KOH (a) and H_3PO_4 (b), and sand before and after reaction (c)

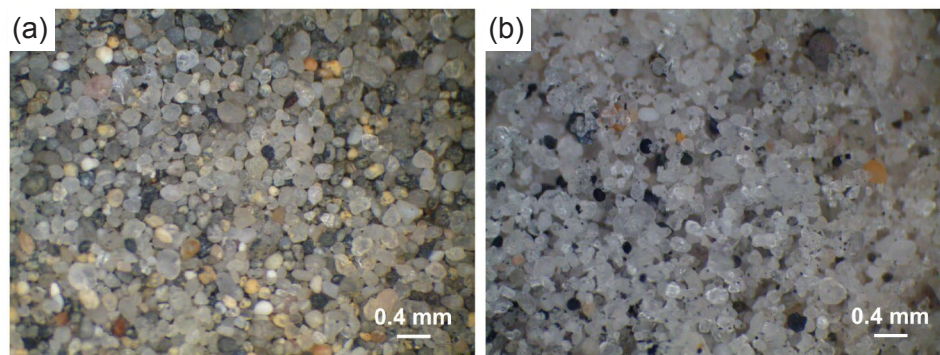


Fig. 4: Photomicrograph of used sand after oolitic content test by KOH method (a) and H_3PO_4 method (b)

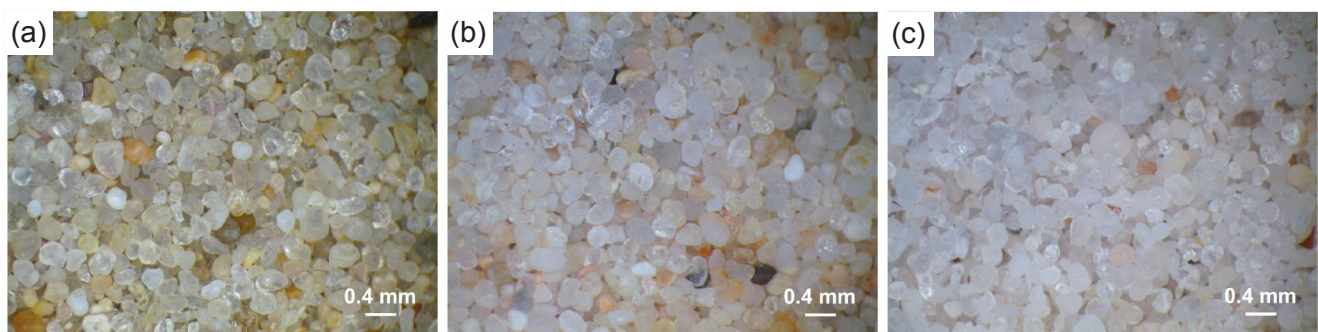


Fig. 5: Photomicrograph of new sand before oolitic content test (a), after KOH method (b), after H_3PO_4 method (c)

3.2 Products by potassium hydroxide repeated approximation method

The typical test results of a sample from the production line are shown in Table 1. The pretreated sample reacted with KOH for 4 times, and the mass change of each reaction was analyzed by potassium hydroxide repeated approximation method. After the first reaction, the mass decreases by 1.52 g. After the second reaction, the mass decreases by 1.09 g. The mass reduction after the third reaction is 0.38 g, which is similar to that of the blank control, indicating that the chemical activity of the

sample at this time is almost the same as that of clean new sand. Therefore, it can be considered that the oolitic deposits is completely removed after 3 times of reactions. Oolitic content of the sample is calculated to be 14.95%.

Table 1: Measured mass values of sample after reacted with KOH for four times

ΔM (g)	M_0 (g)	M_1 (g)	M_2 (g)	M_3 (g)	M_4 (g)
0.5	20	18.48	17.39	17.01	16.78

During the reaction process of the multi-step potassium hydroxide approximation method, only minor etching occurs to the sand in each step, removing just a thin layer from the surface. The color of the sand gradually turns whiter as the number of reactions increases, as illustrated in Fig. 6. When reacting with the oolitic deposits, although there is a relatively larger mass reduction, the sand's color does not become

excessively white. However, once the oolitic deposits are fully reacted and SiO_2 begins to be etched, despite a relatively smaller reduction in mass, the sand's color turns significantly whiter. At this stage, the mass reduction per single reaction is generally near ΔM , indicating that the oolitic deposits have been completely removed, and the testing can be terminated. This ensures that SiO_2 is not over-etched during the testing process.

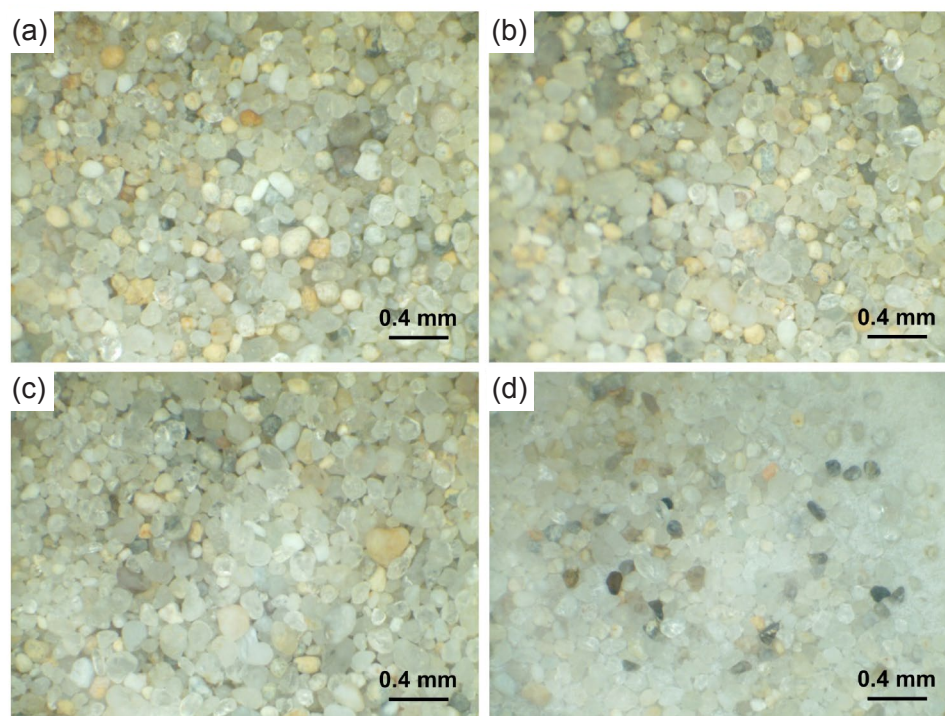


Fig. 6: Photomicrograph of used sand reacted once (a), twice (b), three times (c), and four times (d) with KOH

The principle of this method is proved to be effective by SEM, as shown in Fig. 7. The surface of the pretreated sand that hasn't reacted with KOH has coated oolitic deposits, which is rough in the low-magnification image [Fig. 7(a)]. The oolitic deposits are a porous layered structure in high-magnification image [Fig. 7(b)]. After reacting with KOH once, the coarse oolitic deposits can still be seen on the sand surface [Fig. 7(c)]. High-magnification image [Fig. 7(d)] shows that the oolitic deposits on the surface are corroded and fluffy. At this time, KOH mainly reacts with the oolitic deposits, and the reaction is relatively strong, so the surface changes are obvious. After reacting with KOH twice, the surface of sand particles basically becomes smooth [Fig. 7(e)]. This is also because it is mainly the oolitic deposits that reacts with KOH. However, rough areas can still be seen in the high-magnification image [Fig. 7(f)], indicating that there is still a small amount of oolitic deposits left at this time. After reacting with KOH three or four times, the surface of the sample is smooth and dense [Figs. 7(g, i), and no rough area is found under the high-magnification image [Figs. 7(h, j)], which indicates that the oolitic deposits are completely removed after three times of reaction. At this time, KOH reacts with the sand particles, and the resistance of SiO_2 to KOH corrosion is much stronger than that of the oolitic deposits, so the surface remains

smooth. These morphological changes are consistent with the results of mass changes in Table 1.

The result of EDS is shown in Fig. 8. The oolitic deposits formed by sintering bentonite containing Al element, while the new sand does not, so the existence of the oolitic deposits on the surface can be judged by the Al content. The Al content (atomic ratio) on the surface of the samples that does not react with KOH, reacted once with KOH, and reacted twice with KOH is 9.03at.%, 10.95at.%, and 8.61at.%, respectively. Since these results are similar, the thin layer could be considered the oolitic deposits. The Al content on the sample surface reacted with KOH three times is 1.53at.% and it can be considered that the oolitic deposits have been completely removed. All in all, the SEM and EDS results verify that the oolitic deposits are removed after three times of reactions and prove that the new method for oolitic content is accurate.

3.3 Application of potassium hydroxide repeated approximation method

The oolitic content of the same batch of used sand was tested using the KOH method, H_3PO_4 method (at 400 °C), and the new method, respectively, the results are presented in Fig. 9. The KOH method yields the lowest result, at 16.1%, within a relatively reasonable range. The H_3PO_4 method produces

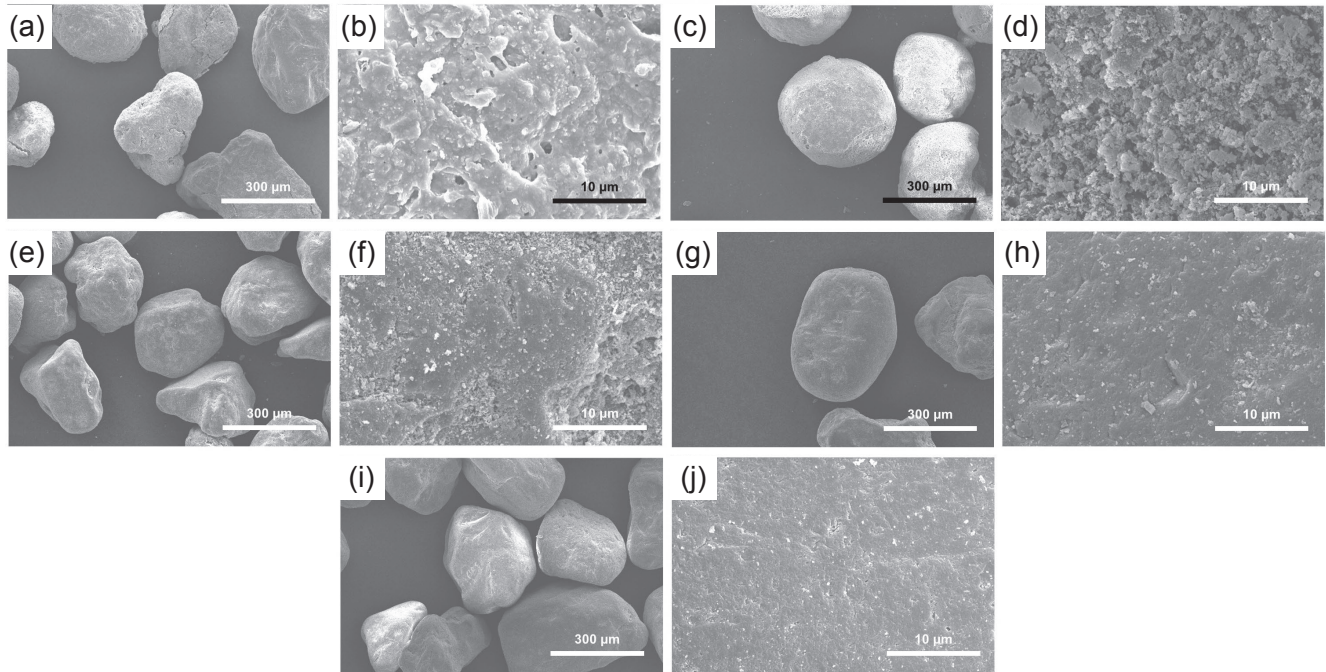


Fig. 7: SEM images of samples before reacting (a, b), reacted once (c, d), twice (e, f), three times (g, h), and four times (i, j) with KOH

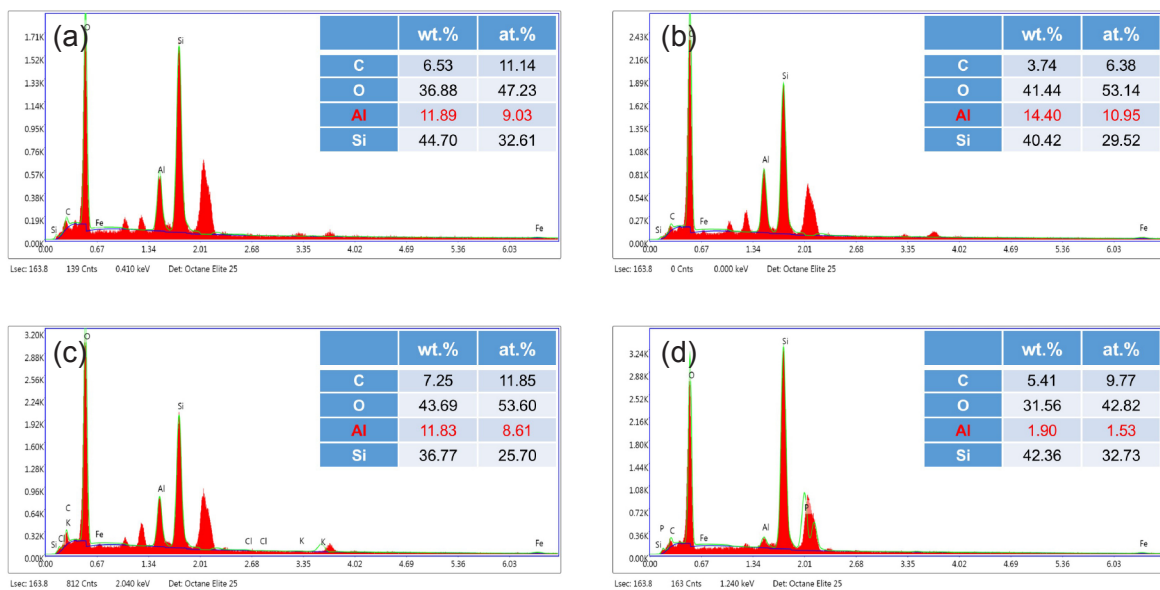


Fig. 8: EDS results of samples before reacting (a), reacted once (b), twice (c), three times (d) with KOH

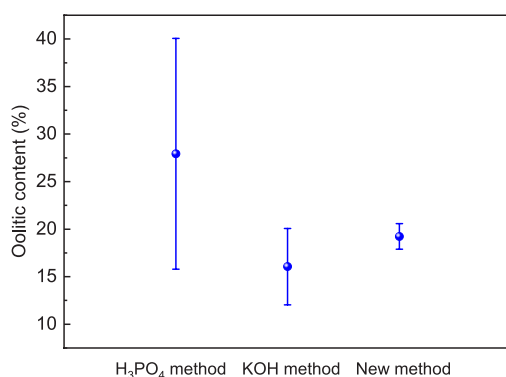


Fig. 9: Results and standard deviations of different oolitic content test methods

the highest result at 28.0%, with significant variability and potential error. The new method's result, at 17.2%, is comparable to that of the KOH method. Notably, the standard deviation of the new method (1.6%) is significantly reduced compared to the H₃PO₄ method (12.1%) and KOH method (4.0%). This demonstrates a substantial improvement in the stability of the new method.

To investigate the practicability of the used sand treated by new method for foundries, the used sand from three production lines of Huangshi Dongbei Foundry Co., Ltd. was collected and tested for the changes in oolitic content within a week. The results are shown in Fig. 10. In the first two days, each batch of samples was tested three times for the oolitic content,

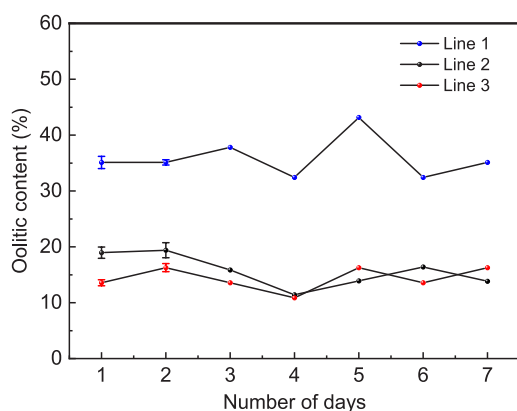


Fig. 10: Practicability of new method on three production lines in a week

and the error value of the same batch is basically within $\pm 1\%$, indicating good repeatability of the results. The oolitic content of the production line 1 is between 30% and 45%, while the oolitic content of the production line 2 and line 3 is between 10% and 25%. It can be seen that this method can properly reflect the change of oolitic content on the production line and provide a basis for controlling the quality of molding sand.

These three production lines are all vertical parting injection molding lines, with a production efficiency of 300 to 500 molds per hour. On production line 1, about 4 t new sand are added daily. On production line 2 and line 3, in addition to 4 t new sand, approximately 4 t to 6 t of collapsed coated core sand is mixed into molding sand per day (the amount of collapsed core sand is estimated to be 70% of the weight of the sand core). Therefore, the accumulation of oolitic deposits in production line 2 and line 3 is much slower than that in production line 1. Production line 1 with a high oolitic content tends towards sand sticking, mainly used for producing ductile iron castings with simple structures. Production line 2 and line 3 can produce ductile iron and gray cast iron castings with complex structures.

4 Conclusion

A new measure by repeated approximation with potassium hydroxide was proposed to test the oolitic content. It includes pretreatment operation, blank control group design, repeated reactions, and calculation of oolitic content.

Through standard pre-treatment operation, impurities such as mud and residual organic matter in the sand can be removed. Through the blank control group, the extent of the reaction of new sand and KOH can be obtained, providing a criterion for the termination of repeated reactions. Through the method of repeated reaction approximation, the oolitic deposits can be accurately removed without excessive corrosion of SiO_2 , and the accurate oolitic content can be obtained.

For a sample from Huangshi Dongbei Foundry Co., Ltd., the mass changes during the test show that the oolitic deposits are completely removed after the third reaction, and the oolitic content is 14.95%. SEM shows that the surface of unreacted

sand has rough and porous oolitic deposits, while the sand becomes smooth after the third reaction. EDS also shows that the Al content on the surface decreases significantly after the third reaction. It shows that the new method can accurately measure the mass change of the sample when the oolitic deposits are just completely removed.

The oolitic content of used sand on the production line of Huangshi Dongbei Foundry Co., Ltd., was tested, and the fluctuation range of repeated test results of the same batch of samples is not more than $\pm 1\%$. The level and the fluctuation of oolitic content of any production line can be obtained through multiple potassium hydroxide approximation method. Thus, the effectiveness, reliability, and practicability of this method are proved.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- [1] Ravi S, Lafay V, Thiel J. Evaluation of physical, performance and emission characteristics of green sand. *International Journal of Metalcasting*, 2019, 13(3): 528–535.
- [2] Ghormley S, Williams R, Dvorak B. Foundry sand source reduction options: Life cycle assessment evaluation. *Environments* (Basel, Switzerland), 2020, 7(9): 66.
- [3] Sadarang J, Nayak R K, Panigrahi I. Challenges and future prospective of alternative materials to silica sand for green sand mould casting: A review. *Transactions of the Indian Institute of Metals*, 2021, 74(12): 2939–2952.
- [4] Belousov P, Chupalenkov N, Christidis G E, et al. Carboniferous bentonites from 10th khutor deposit (Russia): Composition, properties and features of genesis. *Applied Clay Science*, 2021, 215: 106308.
- [5] Eren E, Afsin B. An investigation of Cu(II) adsorption by raw and acid-activated bentonite: A combined potentiometric, thermodynamic, XRD, IR, DTA study. *Journal of Hazardous Materials*, 2008, 151(2–3): 682–691.
- [6] Wei P, Zheng Y, Xiong Y, et al. Effect of water content and structural anisotropy on tensile mechanical properties of montmorillonite using molecular dynamics. *Applied Clay Science*, 2022, 228: 106622.
- [7] Schiebel K, Jordan G, Kaestner A, et al. Effects of heat and cyclic reuse on the properties of bentonite-bonded sand. *European Journal of Mineralogy* (Stuttgart), 2018, 30(6): 1115–1125.
- [8] Boek E S. Molecular dynamics simulations of interlayer structure and mobility in hydrated Li-, Na- and K-montmorillonite clays. *Molecular Physics*, 2014, 112(9–10): 1472–1483.

- [9] Bhuiyan I U, Mouzon J, Schroppel B, et al. Microstructure of bentonite in iron ore green pellets. *Microscopy and Microanalysis*, 2014, 20(1): 33–41.
- [10] Subramanian N, Whittaker M L, Ophus C, et al. Structural implications of interfacial hydrogen bonding in hydrated wyoming-montmorillonite clay. *Journal of Physical Chemistry: C*, 2020, 124(16): 8697–8705.
- [11] Tang S Y, Yang L, Fan Z T, et al. A review of additive manufacturing technology and its application to foundry in China. *China Foundry*, 2021, 18(4): 249–264.
- [12] Khan M M, Mahajani S M, Jadhav G N, et al. Determination of recycle potential in waste green foundry sand through spatiotemporal analysis of sand mold. *Cleaner Engineering and Technology*, 2021, 5: 100329.
- [13] Alabarse F G, Conceição R V, Balzaretti N M, et al. In-situ ftir analyses of bentonite under high-pressure. *Applied Clay Science*, 2011, 51(1–2): 202–208.
- [14] Schiebel K, Jordan G, Kaestner A, et al. Effects of heat and cyclic reuse on the properties of bentonite-bonded sand. *European Journal of Mineralogy (Stuttgart)*, 2018, 30(6): 1115–1125.
- [15] Holtzer M, Bobrowski A, Żymankowska-Kumon S. Temperature influence on structural changes of foundry bentonites. *Journal of Molecular Structure*, 2011, 1004(1–3): 102–108.
- [16] Khan M M, Mahajani S M, Jadhav G N. Transformation of bentonite used in green sand molds during metal casting process and its relevance in sand reclamation. *Applied Clay Science*, 2021, 206: 106072.
- [17] Żymankowska-Kumon S, Holtzer M, Olejnik E, et al. Influence of the changes of the structure of foundry bentonites on their binding properties. *Materials Science*, 2012, 18(1): 57–61.
- [18] Hofmann F, Head S R D G, Fischer L, et al. Property changes and conditioning of repeatedly circulating foundry system sands. *Transactions of the American Foundry Society*, 1967, 75(24): 338–352.
- [19] Kurokawa Y, Kambayashi H, Ota F, et al. Effects of oolitics on green sand properties and casting defects. *Transactions of the American Foundry Society*, 2001, 9: 799–808.
- [20] Zhou C Y, Zhang X J, Zhang F, et al. Review of study on oolitization of used-clay-sand. *Hot Working Technology*, 2012, 41(3): 34–37. (In Chinese)
- [21] Zanetti M C, Fiore S. Foundry processes: the recovery of green moulding sands for core operations. *Resources, Conservation and Recycling*, 2003, 38(3): 243–254.
- [22] Fiore S, Zanetti M C. Industrial treatment processes for recycling of green foundry sands. *International Journal of Cast Metals Research*, 2013, 21(6): 435–438.
- [23] Dietert H W, Praski R, Hofmann F, et al. The “silica program”-measuring performance of system sands. *Transactions of the American Foundry Society*, 1975, 83: 233–244.
- [24] Khan M M, Mahajani S M, Jadhav G N, et al. Mechanical and thermal methods for reclamation of waste foundry sand. *Journal of Environmental Management*, 2021, 279: 111628.