IOP Conf. Series: Materials Science and Engineering **423** (2018) 012103 doi:10.1088/1757-899X/423/1/012103

Preparation and Characterization of the Lightweight Fired Brick with Low-silicon Iron Tailings

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Abstract. This research investigated the possibility of using low-silicon iron tailings together with bentonite, feldspar and rice husk to prepare lightweight fired brick. The bulk density and compressive strength of the lightweight fired brick with different raw material proportions and sintering temperature were studied. The mineral compositions, microstructure and sintering mechanism of the samples were analyzed by XRD and SEM. The results showed that the optimal incorporation amounts of iron tailings, bentonite, feldspar and rice husk were 40%, 30%, 10% and 8% by weight, and the suitable sintering system was 900°C for 1.5h. Under these conditions, the bulk density and compressive strength of the lightweight fired brick were 1.2294g/cm^3 and 7.4MPa, respectively. The primary mineral phases of the sample were hematite, muscovite, mullite, quartz, anhydrite and microcline, which were mainly responsible for the mechanical strength of the samples, and the analysis of microstructures revealed the evenly distributed and interconnected pores and the molten minerals made contributions to the tailing brick good properties.

1. Introduction

Iron ore tailings (IOTs) are the by-product produced in the beneficiation process of iron ore under certain technologies and economic conditions. With the rapid development of modern production, the demand of iron and steel in China's market has increased significantly, which has also prompted mining companies to expand their beneficiation scale, leading to the accumulation of large amounts of IOTs. In China, the annual production amount of IOTs is close to 1.8 billion tons and has been increasing year by year [1]. IOTs are massively accumulated in the mining area, which not only occupies large amounts of land and pollutes the local environment, but also brings great maintenance pressure and safety hazards. In order to alleviate environmental pressure and improve economic efficiency, the comprehensive utilization of iron tailings has been receiving extensive attention from the international community, such as the recovery of valuable elements, soil conditioners and raw materials for building materials [2].

The lightweight wall materials often refer to some non-bearing perforated insulation board such as polystyrene board and polystyrene foam board prepared from organic materials. The lightweight fired brick is a type of eco-friendly building materials replacing normal wall bricks with the characteristics of low density, thermal and sound insulation and high strength. Many studies have proved that IOTs are mainly composed of SiO_2, Al_2O_3, Fe_2O_3, CaO and MgO, which are similar to the natural raw materials of the building materials [3,4], so IOTs can be used as the substitution of natural materials for the preparation of construction bricks. Recently, many studies have focused on preparing building materials by IOTs, especially, bricks, tiles and autoclaved bricks [5-10]. Nevertheless, hardly any research about using low-silicon iron tailings and rice husk to produce lightweight fired bricks has been reported.

This study aims at developing a lightweight fired brick using low-silicon iron tailings as the main raw material and rice husk as the pore-forming agent. This lightweight fired brick makes full use of the solid wastes of IOTs and rice husk, and it also meets the requirements of the country's green production and energy saving. By analyzing the physical properties of the lightweight fired bricks, we could determine the appropriate formulation and conditions. Meanwhile, the microstructures of the lightweight fired brick were also studied in detail.

2. Experimental

2.1. Raw materials

The IOTs were sourced from the Xiyeshan tailings dam in the eastern Hubei province of China. Bentonite acted as a binder in the sintering process to make the bricks stronger, and it was taken from Xinyang City, Henan Province. Feldspar as a fluxing agent is an aluminosilicate mineral containing quartz, albite, montmorillonite and potassium feldspar, which can significantly reduce the sintering temperature. It was taken from Lingshou County, Hebei Province. Rice husk as a pore-forming agent. The cellulose and hemicellulose in the rice husk were decomposed during the sintering process, and the lignin softened and decomposed to form pores to achieve pore formation in the sintering process. The rice husk was taken from Xiantao City, Hubei Province. The main chemical compositions of the raw materials were listed in Table 1, and the X-ray diffractometer (XRD) patterns of the IOTs, bentonite and feldspar were shown in Figure 1.

Table 1. Chemical compositions of the raw materials (wt.%)

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	SO_3	IOL
IOTs	35.43	10.41	10.89	13.01	9.70	1.27	0.87	0.42	5.98	7.95
Bentonite	63.77	14.05	3.01	1.31	2.28	1.32	0.85	0.29	0.13	11.50
Feldspar	64.54	18.68	0.52	0.24	0.11	10.80	1.23	0.02	0.06	0.34

2.2. Experimental methods

The mixtures with different proportions of IOTs, bentonite, feldspar and rice husk were firstly dry-mixed for 10min, and then a certain amount of water was added and stirring was continued for 15 minutes. The moistened granules were pressed into cylinder with dimension of Φ50×50mm for producing brick samples using a hydraulic press. The samples were molded at a pressure of 7.5MPa and dried at 105±5°C for 24hours. Then, the dried samples were fired in a muffle furnace at a rate of 10°C/min to a desired sintering temperature for 1.5 hours, and the samples were cooled naturally to obtain the lightweight fired bricks.

The compressive strength of the fired brick was measured by a press testing machine (YES-100), and the bulk density was performed in accordance with the methods described in Test Methods for Wall Bricks (GB/T2542-2003). The chemical compositions of raw materials were identified by Inductive Coupled Plasma Emission Spectrometer (ICP) (IRIS Advantage Radial). The mineralogical compositions of the raw materials and the fired samples were determined through XRD (D/MX-IIIA) with Cu Kα radiation, voltage 40 kV, current 30 mA and at the scanning rate of 15°/min from 5° to 70°. The microstructures of fired samples were observed by SEM (PHILIPS XL30 TMP).

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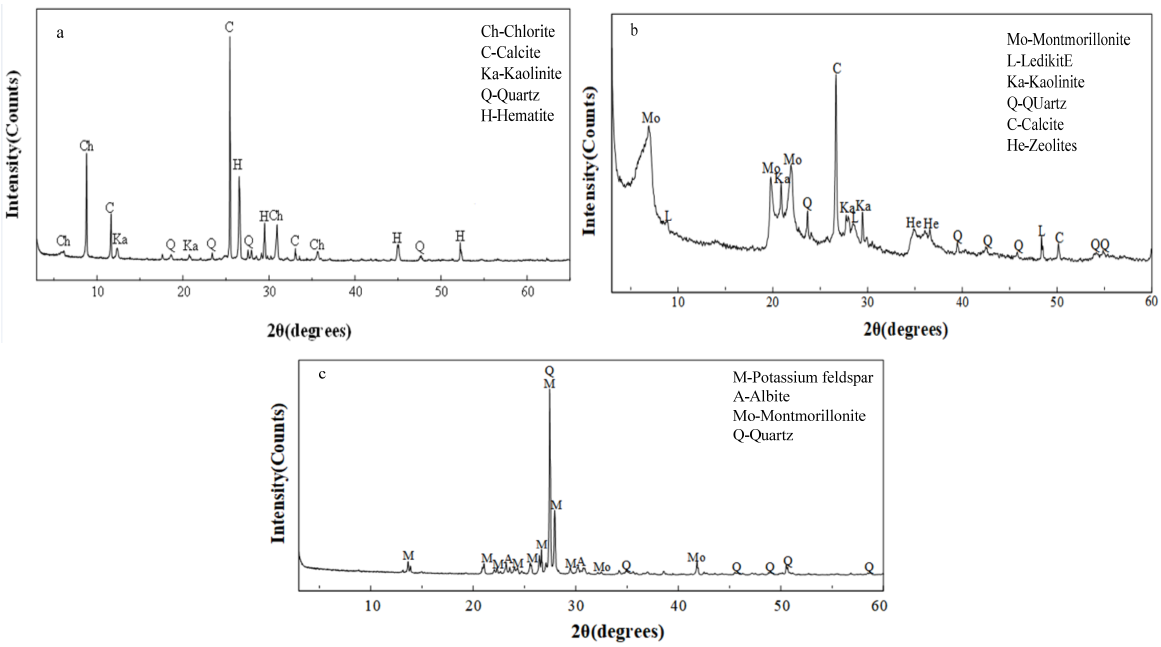

Figure 1. The XRD patterns of IOTs (a), bentonite (b) and feldspar (c)

3. Results and discussion

3.1. Effect of raw materials formulation on the properties of the lightweight fired bricks

Orthogonal experiments can not only reduce test cases and test workloads, but also facilitate the analysis of influencing factors, so the orthogonal experiment was used to determine the appropriate formulation. The orthogonal test with three factors (IOTs, bentonite, and rice husk) and three levels were designed to investigate the optimum formulation. According to foregoing probe tests, the content of feldspar with 10% by weight was conducive to the physical properties of tailing brick. The dried samples were sintered at 900℃ for 1.5 hours. The factors and levels of IOTs, bentonite and rice husk were shown in table 2, and the table 3 showed that the effect of different factors and the corresponding properties of the lightweight fired bricks.

From table 3, it could be seen that $R_{tC}>R_{tA}>R_{tB}$, so the incorporation of rice husk had the greatest influence on the bulk density of the lightweight fired bricks. The main reason is that the pore-forming capacity of rice husk can significantly increase the porosity of the samples and result in lower bulk density [11]. And it was also shown that $R_{kB}>R_{kC}>R_{kA}$, so bentonite had the greatest impact on the compressive strength of the samples. At high temperature, the molten bentonite bound the particles and enhanced the compactness between the particles to increase the compressive strength of the samples [12]. Simultaneously, the SiO_2 and Al_2O_3 rich in bentonite can form mullite during high-temperature sintering, thereby increase the compressive strength of the samples.

Table 2. Factors and levels

Levels	IOTs (A/%)	Bentonite (B/%)	Rice husk（C/%）
1	40	20	6
2	45	25	7
3	50	30	8

According to the consequences from orthogonal tests and cost consideration, the optimum formulation was $A_1B_3C_3$, it meant that the optimal incorporation amounts of iron tailings, bentonite and rice husk were 40%, 30% and 8%, respectively.

Table 3. Effect of different factors on the properties of the lightweight fired bricks

No.	IOTs (A)	Bentonite (B)	Rice husk (C)	Bulk density (g/cm^3)	Compressive strength (MPa)
1#	1	1	1	1.3452	10.2
2#	1	2	2	1.2731	9.3
3#	1	3	3	1.2414	8.6
4#	2	1	2	1.3068	7.8
5#	2	2	3	1.3177	8.1
6#	2	3	1	1.4002	12.8
7#	3	1	3	1.2669	5.4
8#	3	2	1	1.3907	10.9
9#	3	3	2	1.4193	15.7
R_t	0.072	0.048	0.104		
R_k	1.30	4.57	3.93		

3.2. Effect of sintering temperature on the properties of the lightweight fired bricks

Sintering temperature had a vital effect on the performance of the samples. When the sintering temperature was too low, the samples were not evenly sintered, and if the sintering temperature was too high, the samples would be easily degenerated and the internal carbonization was severe. Therefore, the sintering temperature needed to be controlled within a reasonable range for gradient experiments. The samples prepared according to the optimal material ratio obtained from the orthogonal experiment were sintered at 800°C, 850°C, 900°C, 950°C, 1000°C, 1050°C and 1100°C for 1.5 hours. The influences of sintering temperature on the properties of the samples were shown in Figure 2.

Figure 2 revealed that as the sintering temperature increased, the bulk density and compressive strength of the samples gradually increased. The rice husk burnt and decomposed violently in the range of 400-600°C, and when the sintering temperature was higher than 800°C, the flowing liquid phase would block the internal pores of the samples, reduced the porosity of the samples, and increased the stress area of the skeleton with the increase of the sintering temperature, which would increase the bulk density and compressive strength of the samples [13].

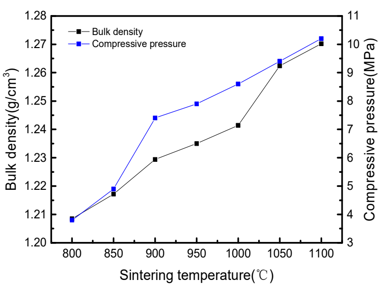

Figure 2. Effect of sintering temperature on the properties of the samples

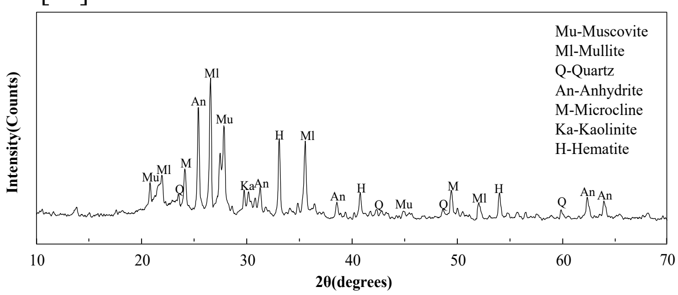

Figure 3. The XRD patterns of the optimum sample

Based on the above discussions, considering the performances and energy savings of the samples, the optimum sintering temperature was 900℃, accordingly, and the bulk density and compressive

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pressure of the obtained sample were 1.2294g/cm^3 and 7.4MPa, respectively. The sample was well conformed to Chinese Fired Common Bricks standards (GB/T5101-2003), furthermore, and the obvious advantage of the lightweight fired brick was lower density compared to common fired bricks with bulk density of 1.8-2.0g/cm^3.Therefore, the lightweight fired bricks can completely replace common fired bricks as a building material from the viewpoint of performance.

3.3. Analysis of the composition and microstructure of the lightweight fired bricks
The samples were prepared according to the above-mentioned experimentally determined optimal formulation and conditions. The mass percentages of IOTs, bentonite, feldspar and rice husk were 40%, 30%, 10% and 8%, respectively. It was pressed under a pressure of 7.5MPa and sintered at 900°C for 1.5 hours. The phases of the sample were characterized by XRD (Figure 3), and the microstructures of the sample can be seen from the micrographs taken using SEM (Figure 4).

3.3.1. X-ray diffraction analysis (XRD). It can be seen from Figure 3 that the main mineral compositions of the lightweight fired brick were hematite, muscovite, mullite, quartz, anhydrite, microcline and a small amount of kaolinite. They acted as the skeleton of the fired sample to improve the strength of the bricks. Compared with the IOTs, bentonite and feldspar XRD patterns (Figure 1), it can be seen that the chlorite, montmorillonite and calcite present in the raw materials disappeared, and new materials such as mullite, anhydrite and muscovite were produced in the samples. It means that some of the minerals in the raw material were decomposed and converted into new material during the sintering process, which in turn enhanced the performance of the samples.

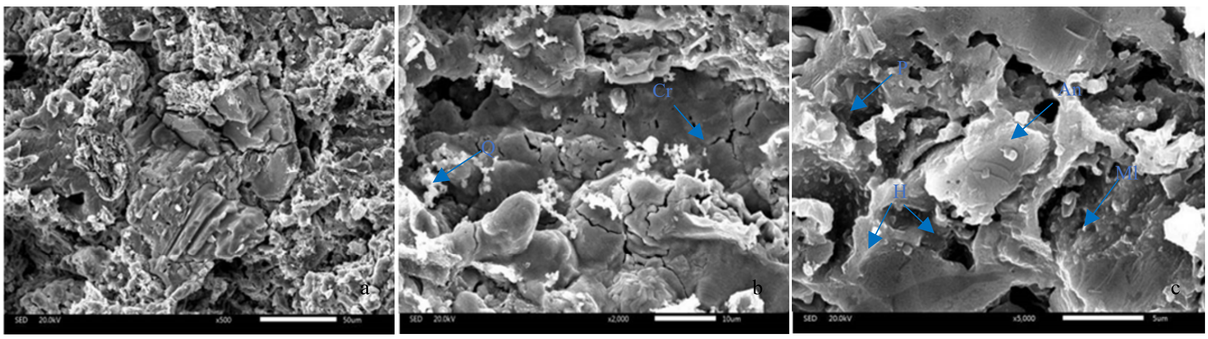

Figure 4. The microstructures of the optimal sample: (a) (500×); (b) (2000×); (c) (5000×)

3.3.2. Scanning electron microscopy (SEM). The microstructure of fractured surface of the fired sample were shown in Figure 4. As shown in Figure 4 (c), there were many micropores (P) on the fractured surface of the sample, and these micropores were interconnected with each other to form a porous structure. It was due to the large amount of gas evolved during the sintering process, and the aggregated micropores contacted each other to form large pores, which resulted in a lower density of the sample. At the same time, a large number of glass phases were evenly distributed, and many different crystals were embedded in the glass phase, which increased the strength of the sample [14]. A lot of microcracks (Cr) can be seen in Figure 4 (b). It was due to the instantaneous escape of large amounts of gas generated by the rapid combustion of rice husk. A thick slab of anhydrite (An) can be seen from Figure 4 (c), and a small amount of aggregated quartz (Q) on the glassy phase can be observed from Figure 4 (b), while the needle mullite (Ml) and kidney-like hematite (H) also existed, and these mineral components were consistent with XRD analysis.

4. Conclusions
In this study, the low-silicon iron tailings were used as the main raw material, and then bentonite, feldspar and rice husk were added to prepare lightweight fired bricks. The conclusions are as follows.

It is feasible to prepare the lightweight fired bricks with low-silicon iron tailings. The optimal incorporation amounts of iron tailings, bentonite, feldspar and rice husk were 40%, 30%, 10% and 8%, respectively, and the optimum sintering temperature was 900℃. The bulk density and compressive strength of the samples, which were prepared under these conditions, were 1.2294g/cm^3 and 7.4MPa, respectively. XRD analysis showed that the main mineral compositions of the lightweight fired bricks were hematite, muscovite, mullite, quartz, anhydrite, microcline and a small amount of kaolinite. SEM analysis showed that there were lots of porous structures with many micropores and irregular pores on the fractured surface of the sample and many different crystals were embedded in the glass phase, which resulted in the lower density and higher strength of the bricks.

Acknowledgements
This research was supported by the Hubei Provincial Education Department (Projects of Science and Technology Research, No. Q20141108), and by the Key Laboratory Foundation Projects of Hubei Province and National Science Foundation of China (No. 41571306).

References
[1] Adiansyah J S, Haque N, Rosano M and Biswas W 2017 Application of a life cycle assessment to compare environmental performance in coal mine tailings management *J. Environ. Manage.* **199** 181-91
[2] Yang C M, Cui C and Qin J 2015 Recycling of low-silicon iron tailings in the production of lightweight aggregates *Ceram. Int.* **41** 1213-21
[3] Prabha P, Marimuthu V, Saravanan M, Palani G S, Lakshmanan N and Senthil R 2013 Effect of confinement on steel-concrete composite light-weight load-bearing wall panels under compression *J Constr. Steel Res.* **81** 11-19
[4] Wang X, Yu H, Li L and Zhao M 2016 Experimental assessment on a kind of composite wall incorporated with shape-stabilized phase change materials (SSPCMs) *Energy Build.* **128** 567-74
[5] Yang C, Cui C, Qin J and Cui X 2014 Characteristics of the fired bricks with low-silicon iron tailings *Constr. Build. Mater.* **70** 36-42
[6] Zhu M, Wang H, Liu L L, Ji R and Wang X 2017 Preparation and characterization of permeable bricks from gangue and tailings *Constr. Build. Mater.* **148** 484-91
[7] Chen Y, Zhang Y, Chen T, Liu T and Huang J 2013 Preparation and characterization of red porcelain tiles with hematite tailings *Constr. Build. Mater.* **38** 1083-88
[8] Zhao Y, Zhang Y, Chen T, Chen Y and Bao S 2012 Preparation of high strength autoclaved bricks from hematite tailings *Constr. Build. Mater.* **28** 450-55
[9] Zhao F Q, Zhao J and Liu H J 2009 Autoclaved brick from low-silicon tailings *Constr. Build. Mater.* **23** 538-41
[10] Ma B G, Cai L X, Li X G and Jian S W 2016 Utilization of iron tailings as substitute in autoclaved aerated concrete: physico-mechanical and microstructure of hydration products *J. Cleaner Prod.* **127** 162-71
[11] Chiang K Y, Chou P H, Hua C R, Chien K L and Cheeseman C 2009 Lightweight bricks manufactured from water treatment sludge and rice husks *J. Hazard. Mater.* **171** 76-82
[12] Raygan S, Abdizadeh H, Dabbagh A and Pourabdoli M 2013 Influence of talc additive on cold strength and reducibility of iron ore sinters compared to bentonite *Ironmaking Steelmaking* **36** 273-278
[13] Krishnarao R V, Subrahmanyam J and Kumar T J 2001 Studies on the formation of black particles in rice husk silica ash *J Eur. Ceram. Soc.* **21** 99-104
[14] Soltan A M M, Pöhler K, Fuchs F, El-Raoof F A, El-Kaliouby A H, Koenig A and Pöllmann H 2016 Clay-bricks from recycled rock tailings *Ceram. Int.* **42** 16685-96