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Effect of sintering technology on properties of coal gangue permeable brick

Yuening Qin[a], Jieguang Song[b,c,*], Yue Liu[c], Yun Xiang[c], Jiangping Liao[c] and Yanrong Zhao[b]
[a]*College of Civil Engineering and Architecture, Guangxi Vocational Normal University, Nanning 530007, China*
[b]*Key Laboratory of New Processing Technology for Nonferrous Metal & Materials, Ministry of Education, Guilin University of Technology, Guilin 541004, China*
[c]*School of Materials and Chemical Engineering, Pingxiang University, Pingxiang 337055, China*

With the continuous mining of coal resources, a large amount of coal gangue is produced, the ecological environment is severely damaged, and the numerous resource wastage is produced. Therefore, the comprehensive utilization of coal gangue should be studied. In this paper, the effect of heating rate, the sintering temperature and the holding time on the performance of permeable bricks is explored, and the following conclusions are drawn. The coal gangue raw materials were ball milled and sieved with a particle size of 100 meshes, the best foaming effect is used to mixed powder ball mill foaming with speed 80 r/min and 3 h ball milling, the firing system is heating rate 2.5 °C/min, the sintering temperature 1050 °C, the holding time is 60min, the performance of permeable brick is the best. After improving the sintering process, the apparent porosity of the permeable brick can reach 55.1%, the compressive strength is 1.42 MPa, and the water permeability coefficient is 1.65×10^{-2} cm/s.

Keywords: Coal gangue, Permeable brick, Sintering technology, Compressive strength, Permeability coefficient.

Introduction

Coal gangue is a black-gray rock associated with coal in the process of the coal formation. However, it is also a of the solid waste produced in the process of coal mining and washing. Coal gangue has a lower carbon content but is harder compared with coal. Statistics as of 2016 indicate that coal storage reached 1.14×10^{12} tons worldwide. The storage of coal in my country was 2.44×10^{11} tons, accounting for 21.4% of the global coal storage. Furthermore, as of 2015, the amount of coal gangue discharged during coal mining reached more than 620 million tons, accounting for approximately 40% of the country's industrial solid waste [1, 2]. As large amounts of coal gangue are piled in open-air areas, vast tracts of land resources are wasted, seriously reducing the arable and forest lands; furthermore, coal gangue is easy to spontaneously combust, and the resultant large amounts of harmful gases eventually damage the ecosystem [3, 4].

Many urban problems have worsened the situation of the surrounding environment. Therefore, with the aim of solving the urban problems and alleviating the ever-increasing ecological dilemmas, the country has embarked on promoting the concept of sponge cities [5-7]. Inseparable from the sponge city concept is the research and development and application of permeable bricks. The permeable brick is a new type of permeable and environmentally friendly porous material, and its brick concrete structure contributes to their excellent properties, such as good chemical stability, compressive strength, water permeability, high-temperature resistance, noise reduction, and sound absorption, etc. Permeable bricks can help to relieve urban drainage pressure, save water resources, increase surface water supply, etc. [8, 9].

The large amount of coal gangue mineral resources in our country has not been used rationally and effectively, resulting in the occupation of vast tracts of lands and the destruction of their surrounding environment [10, 11]. The permeable brick is a new type of environmentally friendly porous material that can be used to build sponge cities. The use of coal gangue to prepare permeable bricks not only conforms with the scientific concept of sustainable development in my country, but it can also solve the various problems caused by coal gangue. Permeable bricks can be used to construct sponge cities and realize the recycling of resources [12, 13].

This study investigates the influences of varying the heating rates, sintering temperatures and insulation, and holding time on the water permeability, apparent porosity, and compressive strength of the permeable bricks, and finally the best sintering process parameters for the preparation of permeable bricks.

*Corresponding author:
Tel : +86 799 6338787
Fax: +86 799 6682222
E-mail: 45102808@qq.com

Table 1. Composition analysis of coal gangue.

Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	TiO_2	K_2O+NaO	V_2O_5	P_2O_5
Content(wt%)	55	32	5.2	0.8	1.86	2.85	2.13	0.01	0.15

Experimental Materials and Methods

The chemical composition of the coal gangue is shown in Table 1. The X-ray diffraction of the coal gangue is shown in Fig. 1. The coal gangue used as the raw material in this study was poured into a ball mill and mixed evenly. The calculated average particle size was 6 μm. The obtained waste coal gangue was crushed, and then the coarser pieces were put into the ball milling tank and milled again into a ball. The ratios of various components with coal gangue as a raw material for preparing permeable bricks were determined via multiple experiments and comparative analysis. The objective was to determine the best ratio of coal gangue, kaolin, sintering aid, and foaming agent. After obtaining the results, ball milling and foaming were conducted, and the sample was dried and demolded and subsequently sintered at a high temperature according to the sintering temperature range. By varying and testing the compressive strength, water permeability, apparent porosity, and other properties of the sample, the changes in performance of the material could be explored. The density of the sintered samples was determined using an AR2140 electronic balance, and the porosity of the samples was determined with respect to theoretical density. The water permeability coefficients of the samples were measured via the stable water pressure method according to the standard of permeable pavement bricks and permeable road panels (GB/T25993-2010). The phase separation and microstructure of the samples were determined using a D8 advance X-ray diffractometer and an SU8010 scanning electron microscope (SEM), respectively.

Results and Discussion

The influence of sintering temperature on the performance of coal gangue permeable brick

Figure 2 shows that the porosity increases continuously beginning from the sintering temperature of 950 °C. The main reason is that when the green body is sintered, particles in the green body appear gradually. The green body undergoes physical and chemical changes, but these changes are not significant when the temperature is low. As the sintering temperature continuously increases, the blowing agent and impurities of the coal gangue continue to emit gas. This phenomenon manifesting at high temperatures increases the porosity within the green body, hence the better water permeability. With the further increase in temperature, particularly when the temperature reaches 1050 °C, the porosity reaches the peak of 55.1%. Furthermore, the glass phase continues to appear, and the volume density of the green body gradually increases, resulting in a decrease in porosity. When the sintering temperature reaches 1200 °C, the body starts to become dense, and the porosity decreases significantly to 31.9%. In particular, the free water in the

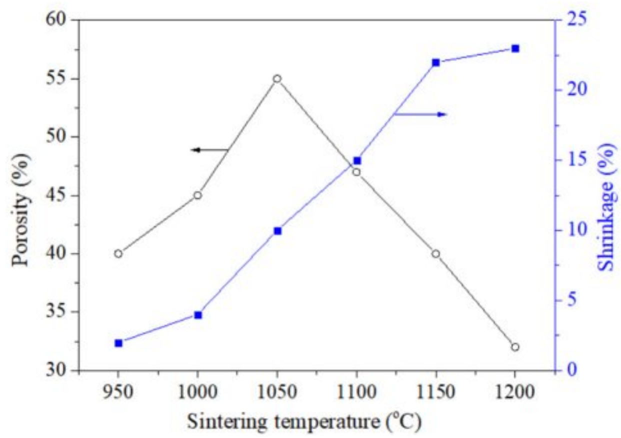

Fig. 2. The influence of sintering temperature on porosity and shrinkage of brick.

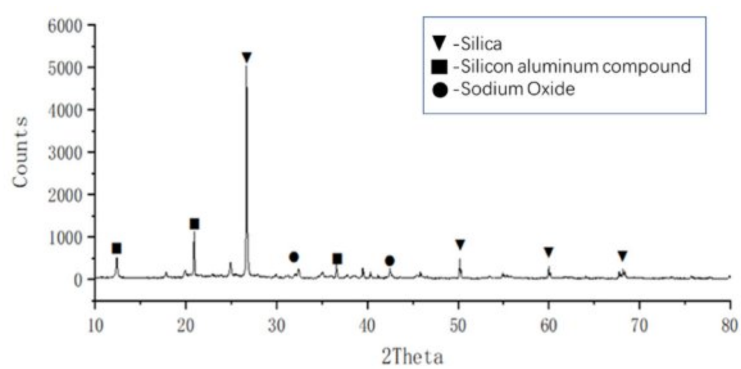

Fig. 1. Phase analysis of coal gangue.

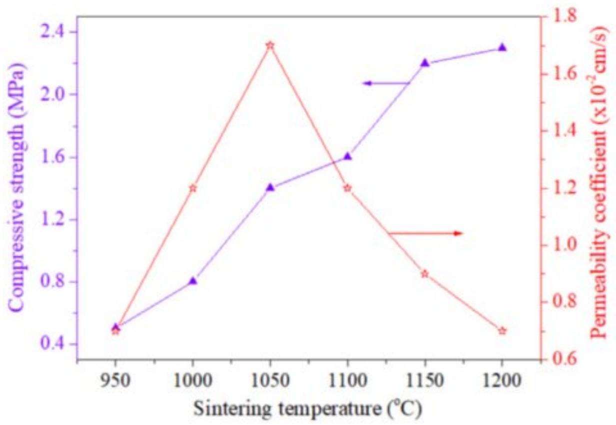

Fig. 3. Effect of sintering temperatures on the compressive strength and permeability coefficient of brick.

green body is eliminated between 950 °C to 1200 °C, the oxidation of the substances causes the particles to move closer, and the shrinkage rate of the green body continues to increase [14, 15]. At 1200 °C, the shrinkage rate of the green body is 23.6%.

Figure 3 shows that as the sintering temperature gradually rises from 950 °C, the compressive strength and permeability coefficient of the sample increase accordingly. When the temperature reaches 1050 °C, the compressive strength is 1.42 MPa, and the water permeability coefficient is 1.65×10^{-2} cm/s. As the temperature continues to rise, the glass phase in the green body continues to appear, the pores are gradually blocked. Furthermore, the green body becomes much denser, which causes the water permeability coefficient to decrease. At the low rate range, the water permeability coefficient of the permeable brick decreases to 0.67×10^{-2} cm/s. When the green body is dense, its structure is stable. The compressive strength of the sample can reach 2.3 MPa.

Figure 4 shows the morphology of the permeable brick sample. When the sintering temperature is 950 °C, the sample's strength is decreased, and its degree of sintering densification is weak. As the sintering temperature increases, the powder drop phenomenon

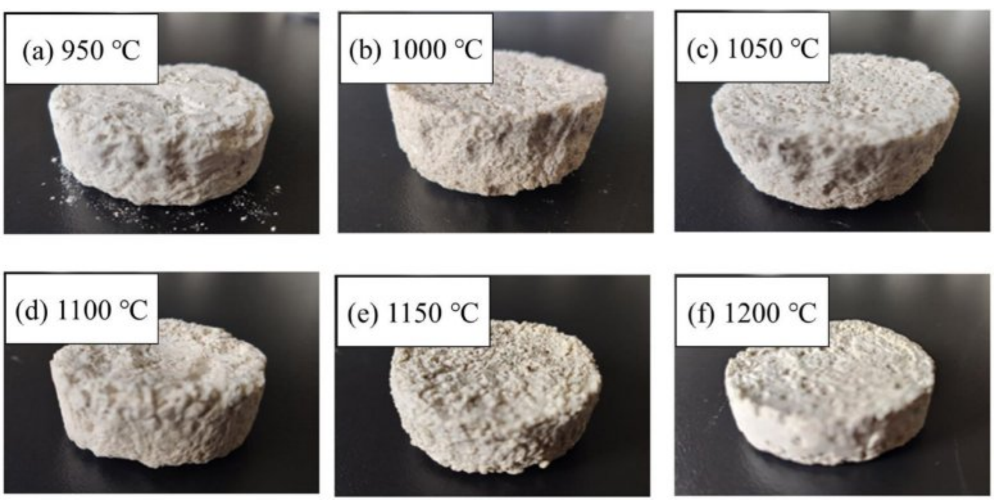

Fig. 4. Physical photos of samples at different sintering temperature.

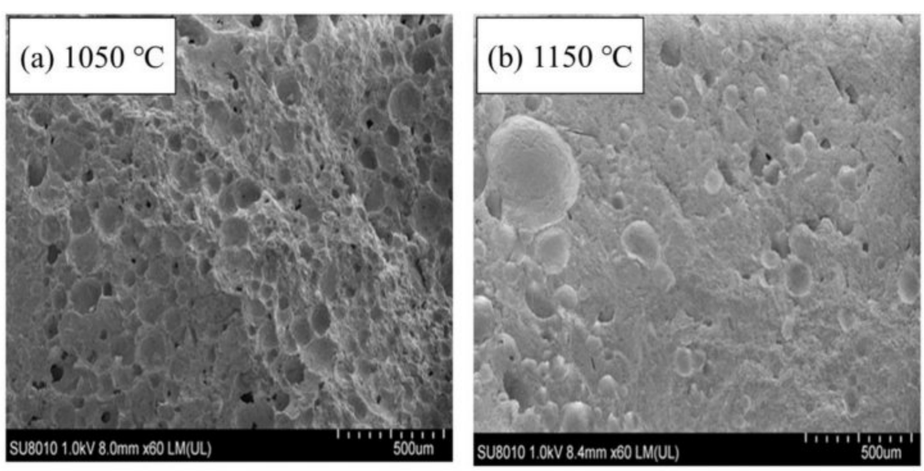

Fig. 5. SEM photos of samples at different sintering temperatures.

gradually disappears, the sintering densification degree of the green body increases, and surface voids are gradually reduced. When the sintering temperature is increased further, the surface voids generally disappear.

As shown in Fig. 5, there are many pores at 1050 °C, but most of them are unevenly distributed. The pore size is also large or small. The largest pore size is 100 µm, while there are a large number of pores at 1150 °C. The surface of bubbles and some pores is relatively smooth. Therefore, combining various factors, it is finally determined that the maximum sintering temperature is 1050 °C, and the water permeability of the green body is the best.

The influence of holding time on the performance of permeable bricks

The influence of holding time on the porosity, compressive strength, and permeability coefficient of the permeable bricks at the sintering temperature of 1050 °C was further studied. As shown in Fig. 6, between 30 to 150 min, the pore rate first decreases and then increases. With this rise in holding time, more of the liquid phase appears, and this liquid phase continues to develop [16, 17]. Filling the voids allows for the porosity to continuously decrease. When the sintering temperature is unchanged, the amount of liquid phase reaches a saturated state. When the amount of liquid phase is unchanged at a maintained temperature, the microbubbles in the liquid phase will eventually burst. At this state, open pores are generated, further increasing the porosity. The entire process, which is driven by the liquid phase, readjusts the internal microstructure of the ceramic to achieve a process of densification. The material reaches a shrinking state, but the shrinkage rate is gradually decreased in the stage.

It can be seen from Fig. 7 that as the holding time continues to increase, the compressive strength continues to increase, and the water permeability first increases and then decreases. As the heat preservation time increases,

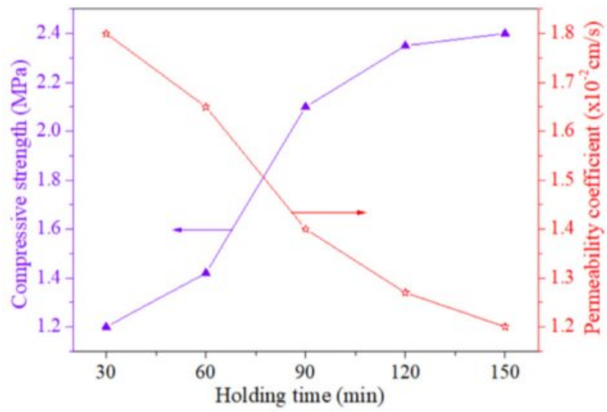

Fig. 7. The effect of holding time on the compressive strength and permeability coefficient of brick.

the porosity gradually decreases and tends to be densified, resulting in a gradual increase in the compressive strength of the brick body, and the water permeability coefficient gradually decreases with the non-densified powder, resulting in blockage of the perforated surface The reduction increases the permeability coefficient. After reaching a certain level, the number of perforations decreases due to the densification effect, resulting in a downward trend in the permeability coefficient. When the holding time is 60 minutes, the permeability coefficient reaches the highest. Therefore, considering the cost of preparing the sample and its performance, it is finally determined that the holding time of the sample is 60 min.

The influence of heating rate on the performance of coal gangue permeable brick

As shown in Fig. 8, the porosity first increases and then decreases at the heating rate of 1.5 °C/min to 4.5 °C/min, but the sintering shrinkage rate shows a decreasing trend. At this increasing heating rate, the entire heating process is shortened, which results further in a shortened sintering process. In other words, as the time needed to reach a certain sintering temperature is reduced, the

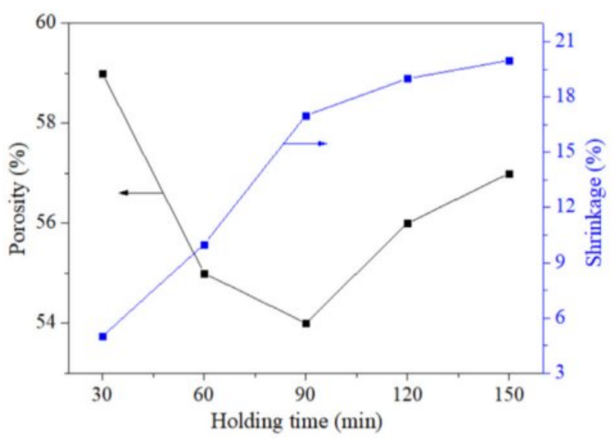

Fig. .6 The effect of holding time on the porosity and shrinkage of brick.

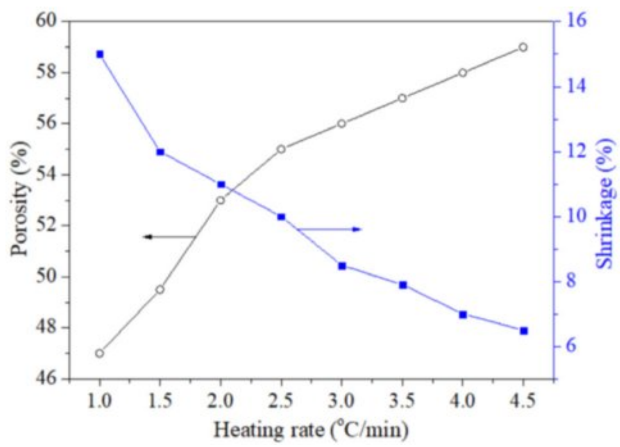

Fig. 8. The influence of heating rate on the porosity and shrinkage of brick.

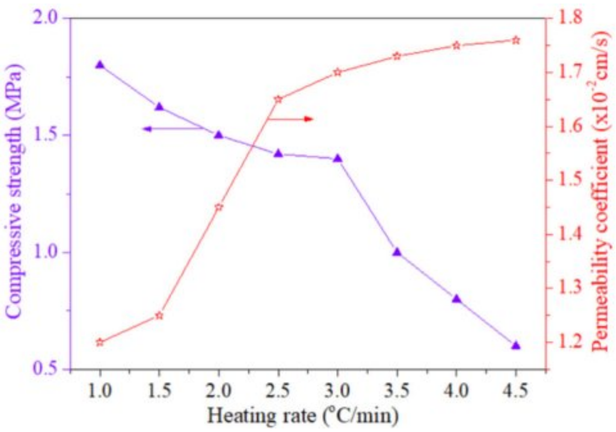

Fig. 9. The influence of heating rate on the compressive strength and permeability coefficient of brick.

sintering densification process is decreased while the porosity is increased; then, after reaching the limit, the rising temperature influences the densification, and the liquid phase generated during the sintering process continues to fill the voids, thus decreasing the porosity [18, 19]. When the heating rate is 2.5 °C/min, the porosity of the blank reaches the maximum. As the heating rate increases, the sintering heating process is shortened, and the sintering time is reduced, hence reducing both the ceramic shrinkage process and the shrinkage rate.

It can be seen from Fig. 9 that the influence of the heating rate on the porosity, compressive strength and water permeability coefficient is obtained. As the heating rate increases, the compressive strength of the permeable brick gradually decreases, while the water permeability coefficient gradually increases. After the rate is increased, the sintering cycle is shortened, the degree of densification of the ceramic material is reduced, and the glass phase is relatively reduced, so the compressive strength of the material is reduced. The heating process is shortened, the more voids are left, the more perforations that cause the material to permeate water, and the water permeability coefficient increases. When the heating rate is increased to 2.5 °C/min, the increasing trend of the water permeability coefficient becomes insignificant, and the compressive strength drops more. Therefore, it is considered that the heating rate of 2.5 °C/min is a better heating rate.

Conclusion

This paper uses coal gangue as the main raw material to prepare permeable bricks, and uses the slurry method to prepare permeable bricks. The effect of heating rate, the sintering temperature and the holding time on the performance of permeable bricks is explored, and the following conclusions are drawn. The coal gangue raw materials were ball milled and sieved with a particle size of 100 meshes, the best foaming effect is used to mixed powder ball mill foaming with speed 80 r/min and 3 h ball milling, the firing system is heating rate 2.5 °C/min, the sintering temperature 1050 °C, the holding time is 60min, the performance of permeable brick is the best. After improving the sintering process, the apparent porosity of the permeable brick can reach 55.1%, the compressive strength is 1.42 MPa, and the water permeability coefficient is 1.65×10^{-2} cm/s.

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