Study on Non-fired Brick Derived from Waste Mud of Slurry Shield Tunnel: Parameters Effect and Long Term Strength

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Abstract. Waste mud generated during the construction of shield tunnels needs to be treated and cleaned before disposal due to its complex material composition. Various technologies are available for the treatment and disposal of waste mud, including sedimentation, filtration, centrifugation, incineration, and solidification. One promising solution is to recycle the waste slurry to produce bricks, which not only helps reduce environmental impact but also provides a cost-effective approach for disposal. The strength of bricks produced from waste mud is affected by several parameters, including the type and proportion of binder, mud properties, drying and firing conditions, and curing time. This study focuses on optimizing the compressive strength of test bricks by varying the formula of the curing agent, molding pressure, material moisture content, and curing agent dosage. The research provides valuable insights for improving the production process of the bricks. Waste mud from a construction site in Zhejiang Province, China, was used, and commercial-grade 525 Portland cement was utilized for hardening the mud into bricks.

Keywords: Waste mud; Slurry shield tunnel; Non-fired brick; Long term strength

1 Introduction

Waste mud from slurry shield tunnel is a type of waste generated during the construction process of shield tunnels [1]. Due to factors such as construction technology and geological environment, the slurry cannot be reused and needs to be treated and cleaned. The amount of waste shield slurry is affected by factors such as tunnel length, diameter, geological conditions, and construction speed [2,3]. Generally speaking, the longer the tunnel, the larger the diameter, and the more complex the geological conditions, the greater the amount of waste slurry generated. The material composition of waste shield slurry is complex. Water is the main component of shield slurry and the basis of slurry [4]. The moisture of mud from slurry shield tunnel is generally between 50% and 90%. Due to the need to cut rocks and soil during shield tunneling, waste mud contains a

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large number of soil particles, the size and composition of which are affected by different geological environments and shield machines [5]. Shield slurry usually requires the addition of some chemical reagents, such as polymers, colloid clays, and foaming agents, to increase the viscosity and fluidity of the slurry. The types and proportions of these additives will affect the material composition of the waste mud.

There are various technologies available for the treatment and disposal of waste mud generated during shield tunnel construction. Some common techniques including sedimentation, filtration, Centrifugation, Incineration and Solidification [6]. Sedimentation involves allowing the suspended solids in the mud to settle to the bottom of a tank or pond through gravity. The clear water can then be discharged or reused, while the settled solids are removed for disposal. The mud is passed through a filter medium, such as sand or a cloth, to remove suspended solids. The filtered water can be discharged or reused, while the filtered solids are removed for disposal. Centrifugation involves spinning the mud at high speeds in a centrifuge to separate the solids from the liquid. The separated solids can then be removed for disposal, while the liquid can be reused or discharged. Incineration involves burning the waste mud at high temperatures to reduce its volume and destroy any harmful substances. The ash produced from incineration must be properly disposed of in a hazardous waste landfill. Solidification is a technique that a binding agent is added to the mud to solidify the waste and reduce its potential for leaching harmful substances into the environment. The solidified waste can then be disposed of in a landfill or used for other applications, such as road construction.

Disposal of waste slurry generated from the construction of shield tunnels has been a challenging task for engineers and researchers. One of the promising solutions is to recycle the waste slurry to produce bricks, which not only helps in reducing the environmental impact but also provides a cost-effective approach for disposal [7]. The production of bricks from waste mud involves several steps, including mud preparation, brick forming, drying, and firing. The waste mud is first treated to remove large particles and then mixed with a binder such as cement, fly ash, or lime to improve the mechanical properties of the bricks. The mixture is then compressed into a desired shape using a brick press or an extruder. After shaping, the bricks are dried and then maintained to enhance their strength and durability.

However, several parameters affecting brick strength. The strength of bricks produced from waste mud is affected by several parameters, including the type and proportion of binder, mud properties, drying and firing conditions, and curing time [7]. The following are the critical parameters that significantly affect the strength of bricks. The type and proportion of the binder have a significant impact on the strength of the bricks. The most commonly used binders are cement and fly ash. The proportion of the binder should be optimized to achieve a balance between strength and cost-effectiveness. The properties of waste slurry, such as particle size, density, and water content, have a direct impact on the strength of the bricks [8]. A higher water content leads to weaker bricks, while a higher particle size distribution results in better strength [9-12].

Therefore, producing non-fired bricks from waste mud is a promising solution for waste disposal, and several technologies have been developed to achieve this [13-18]. The parameters affecting the strength of the bricks, including the type and proportion of binder, mud properties, and drying condition, should be optimized to achieve the desired strength and cost-effectiveness [19-21]. Further research is required to optimize the production process to enhance the quality and strength of the bricks.

This research focused on optimizing the compressive strength of bricks by varying material moisture content, curing agent dosage and skeletal material dosage. By identifying the optimal conditions for producing the bricks. The study provides valuable insights for improving the production process of the bricks.

2 Materials and Method

2.1 Materials and Equipment

Waste mud was collected from the construction site of Zhijiang Road in Zhejiang Province, China. Commercial grade 525 Portland cement, was used to harden the mud into bricks. The standard cement mortar test box (HBY-30CA, Leiyun) was utilized for curing the bricks, while the compressive strength testing machine (YES-300, Xinshiji) was used to determine their compressive strength.

2.2 Curing Experiment

2.2.1 Influence of Material Moisture Content on Compressive Strength of Bricks

Three groups of slurries with different moisture contents (25%, 30%, and 35%) and a designed dosage of 12% for the curing agent were prepared. Parallel samples were set up for each group, and the bricks were molded under a pressure of 20 MPa. The cured bricks were placed in a standard curing box with constant temperature (20±1°C) and humidity (≥90%) until the designated age was reached, and then tested for compressive strength.

Moisture contents (%)=$\left(\frac{m_{wet}-m_{dry}}{m_{wet}}\right)\times 100$

m_{wet}- the mass of feedstock without drying;

m_{dry}-the mass of feedstock with 105°C drying for 2 hours

2.2.2 Influence of Temperature on Compressive Strength of Bricks

The bricks were molded with a moisture content of 30% and a designed dosage of 12% for the curing agent under a pressure of 20 MPa. The bricks were divided into two groups: one was placed in a standard curing box with constant temperature (20±1°C), and the other was placed in a refrigerator with a temperature of 5±1 °C. The cured bricks were tested for compressive strength after reaching the designated age.

2.2.3 Influence of Curing Agent Dosage on Compressive Strength of Bricks.

Three groups of slurries with curing agent dosages of 12%, 15%, and 18% were prepared. Parallel samples were set up for each group, and the bricks were molded under a pressure of 20 MPa. The cured bricks were placed in a standard curing box with constant temperature (20±1°C) and humidity (≥90%) until the designated age was reached, and then tested for compressive strength.

2.2.4 Influence of Adding Skeletal on Compressive Strength of Bricks

A controlled moisture content of 30% was maintained while adding 12% cement and corresponding skeletal (sand) based on the design mix. The bricks were molded under a pressure of 20 MPa and placed in a standard curing box with constant temperature (20±1°C) and humidity

3 Results and Discussion

3.1 The effect of waste mud moisture on compressive strength of brick

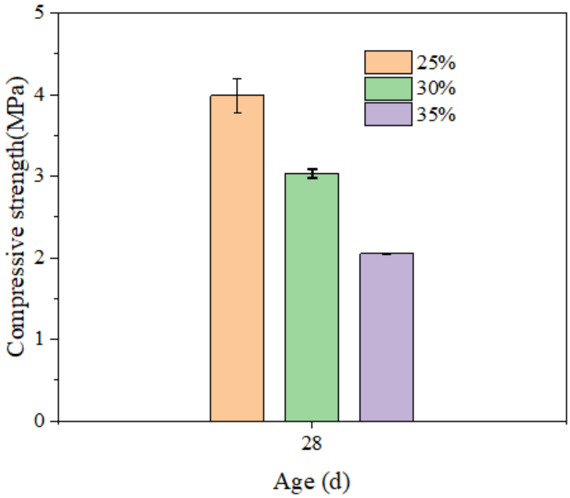

Fig. 1. Influence of waste mud moisture on compressive strength of bricks

In light of the anticipated variability in the dewatering efficiency of the filter press to be acquired for the zhijiang road construction site in Hangzhou, this study emulated the actual working conditions of mud cakes, with moisture levels fluctuating between 25-35%, and proceeded to conduct compressive strength evaluations on bricks constructed from materials featuring varying moisture contents. The findings of the experiments (Figure 1) reveal that an increase in the moisture content of the material correlates with a decrease in the compressive strength of the solidified brick. This is due to the fact that a lower moisture content results in a higher concentration of dry matter per unit volume of brick, leading to the formation of greater mechanical strength. Additionally, a lower moisture content yields a shorter timeframe to establish mechanical strength. Upon the 28 days completion of the curing period, the compressive strength of the bricks in the 35% moisture content test group attained 2.05 MPa, while that of the 25% moisture content test group was measured at 3.99 MPa.

3.2 The effect of maintenance temperature on compressive strength of brick

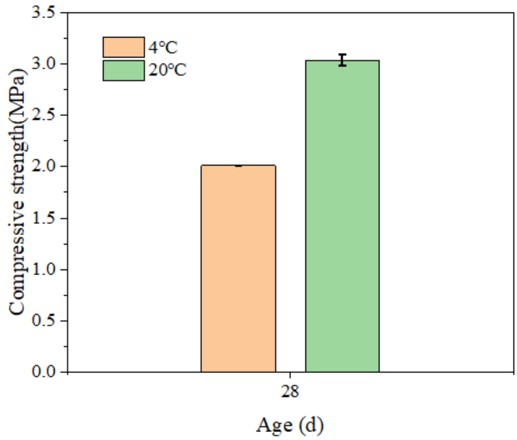

Fig. 2. Influence of maintenance temperature on compressive strength of bricks

This study aimed to investigate the influence of outdoor maintenance conditions during winter on the mechanical strength of masonry bricks. To achieve this, compressive strength tests were conducted on bricks prepared under different maintenance temperatures. The test results, depicted in Figure 2, demonstrated that low temperatures had a significant impact on the compressive strength of the masonry bricks. After a 28-day maintenance period, the compressive strength of the bricks maintained at low temperatures reached approximately 2.00 MPa, while those maintained at room temperature reached around 3.00 MPa.

3.3 The effect of curing agent dosage on compressive strength of brick

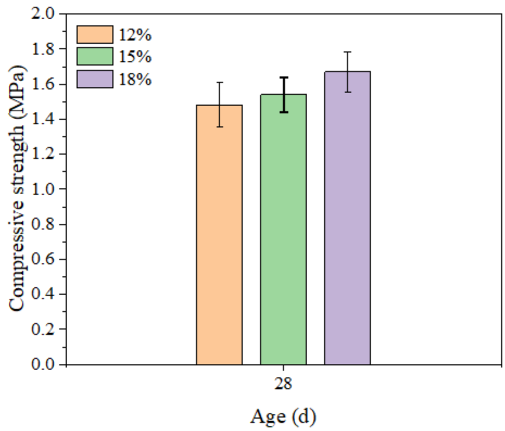

Fig. 3. Influence of curing agent dosage on compressive strength of bricks

The experimental findings, as depicted in Figure 3, indicate that increasing the dosage of the solidifying agent (525 cement) is beneficial in enhancing the compressive strength of masonry bricks. Upon the completion of the 28-day maintenance period, the bricks prepared using a 12% dosage of solidifying agent exhibited a compressive strength of 1.48 MPa, whereas those prepared using an 18% dosage exhibited a compressive strength of 1.67 MPa.

3.4 The effect of skeletal material dosage on compressive strength of brick

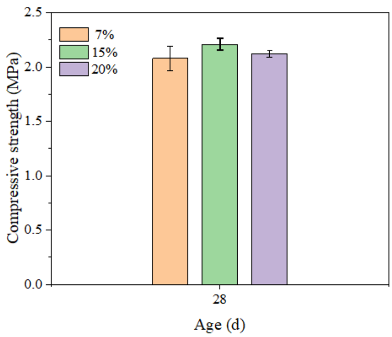

Fig. 4. Influence of skeletal material dosage on compressive strength of bricks

Based on the test results (Figure 4), it was found that the addition of aggregates effectively improved the compressive strength of masonry bricks. The test group with a sand content of 15% achieved the highest mechanical strength, particularly within the short-term 24-hour period, where the compressive strength of the 15% sand content bricks reached 1.35 MPa after 24 hours of maintenance. After the 28-day maintenance period, the compressive strength of the sand-added test group reached 2.00-2.16 MPa.

3.5 The effect of waste mud from different sieving process on compressive strength of brick

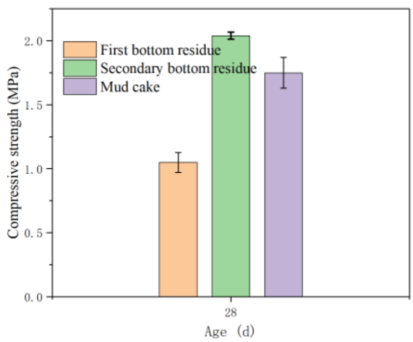

Fig. 5. Influence of waste mud from different sieving process on compressive strength of bricks

Based on the test results (Figure 5), it was found that bricks prepared with secondary bottom residue had the highest compressive strength. After a short-term maintenance period of 24 hours, its compressive strength reached 1.32 MPa, and after 28 days of maintenance, it reached 2.04 MPa. In contrast, bricks prepared with primary bottom residue had lower compressive strength, with only 1.05 MPa after 28 days of maintenance. This suggests that the particle size of the raw materials has a significant impact on the compressive strength of the bricks.

3.6 Strength mechanism of bricks

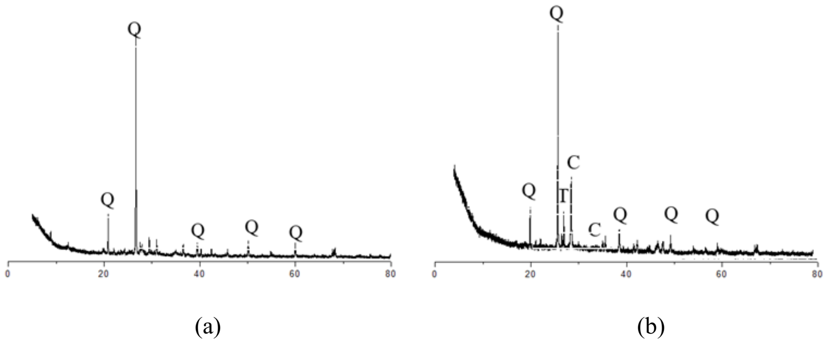

Fig. 6. XRD spectra of a) sediment and b) specimen (Feedstock moisture 30%, curing agent dosage 15%, maintenance temperature 20°C, curing time 28 d; Q stands for quartz, C for calcite, and T for hydrated calcium silicate)

From the XRD test results shown above (Figure 6), it can be observed that the original sediment contains quartz. After 28 days of curing, the peaks of calcite and hydrated calcium silicate become more evident. The results indicate that during the initial stages of hydration reaction, products such as calcium hydroxide and ettringite are formed. As the curing progresses, these initial hydration products continue to participate in reactions, resulting in the formation of hydrated calcium silicate. Furthermore, with an increase in cement content, the amount of hydrated calcium silicate generated in the reaction increases, thereby enhancing the mechanical properties of the samples.

4 Conclusion

This series of studies investigated several factors that influence the compressive strength of masonry bricks, including waste mud moisture, maintenance temperature, solidifying agent dosage, aggregates dosage, and waste mud derived from various sieving processes. The investigation into the effect of waste mud moisture on compressive strength demonstrated that increased moisture content resulted in decreased compressive strength of the bricks. The research into the effect of maintenance temperature on compressive strength revealed that low temperatures had a significant impact on the compressive strength of the bricks. The study on the effect of solidifying agent dosage on compressive strength found that an increase in the dosage of the solidifying agent led to an increase in compressive strength. The exploration into the effect of aggregates dosage on compressive strength found that the addition of aggregates improved the compressive strength of the bricks. Lastly, the analysis of the impact of waste mud from different sieving processes on compressive strength demonstrated that bricks made from secondary bottom residue had the highest compressive strength.

The research findings suggest that controlling waste mud moisture, maintaining optimal maintenance temperature, optimizing the dosage of solidifying agents and aggregates, and utilizing waste mud derived from specific sieving processes can all contribute to the improvement of compressive strength of masonry bricks produced from waste mud. These findings are important for the development of sustainable construction materials and can be applied by practitioners in the construction industry. Acknowledgement

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