Resource Utilization of Waste Mud from Slurry Shield Tunnel: Non-fired Brick Production, Short Term Strength Investigation

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Abstract. The production process of bricks made from waste mud was optimized in this study by investigating the effects of various factors on compressive strength, including curing agent formula, molding pressure, moisture content, and dosage. Economic benefits were also analyzed based on market conditions, demonstrating the high potential of the bricks. The waste mud was identified as fine sand soil consisting mainly of quartz and clay minerals. Portland cement was identified as the optimal curing agent, and higher molding pressure was found to increase compressive strength. Lower moisture content resulted in a shorter time to form mechanical strength. The study also showed that low maintenance temperatures had little effect on early compressive strength. Overall, this process successfully reduces and utilizes waste mud from slurry shield tunnels.

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

1 Introduction

With the acceleration of urbanization in China, traffic congestion problem on the ground is aggravating. The subway construction has become a solution to relieve traffic pressure for major cities [1]. As on 2021, the total length of subway lines in operation in China reached 7253.73 km, accounting for 70% of urban rail transit lines length. Shield method is one of the efficient methods in urban subway tunnel construction and widely used in soft soil area. However, the mud production from shield method is generally 2-3 times as much as that of traditional excavation method [2]. The mud is transported to the surface by a slurry pump or pipe for further treatment. Due to the limited storage space in the city and the high site rental cost, the waste mud from slurry shield requires to be disposal in short time. The waste mud produced during the process is typically composed of excavated soil, bentonite clay, water, and small amounts of other materials [3]. While this waste material can be challenging to dispose of safely and cost-effectively, it can also be a valuable resource with the reasonable treatment and processing.

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One common approach to utilizing waste mud is to extract the bentonite clay and use it as a binder in the construction industry. Bentonite clay has excellent binding properties, making it useful in a range of applications such as soil stabilization, concrete production, and drilling mud. Additionally, through mechanical dewatering, the water content of the waste mud can be reduced, allowing for easier transport and disposal [4]. After dewatering process, the soil component of waste mud can be further processed to create fill materials for land reclamation and construction projects. Proper measures need to be taken to ensure that the waste does not leach into the surrounding soil or water.

Other potential uses for waste mud include using it as a raw material for the production of ceramics, bricks, and other construction materials [5]. This method has several advantages. First, by reusing waste mud as a raw material, the amount of waste generated from the tunneling process can be significantly reduced. This reduces the impact on the environment, and lowers the amount of materials that need to be transported and disposed of. Second, producing construction materials from waste mud can be more cost-effective than traditional methods that require the use of raw materials [6]. This approach can reduce the cost of waste management, and potentially generate revenue from the sale of construction materials. Third, the use of waste mud in the production of construction materials can result in high-quality products. Waste mud contains minerals and other substances that can enhance the properties of ceramics and bricks, such as strength and durability. Overall, the proper treatment and processing of waste mud from slurry shield tunneling can turn it from a disposal challenge into a valuable resource for the construction industry and other applications.

Today's society demands that building materials possess properties of fast transportation and efficient installation due to rapid economic development and high-speed logistics transportation. In order to meet these demands, the short-term mechanical strength of bricks becomes an especially critical factor as it ensures that bricks remain intact during transportation and installation. With urbanization progressing at an unprecedented rate, the construction industry faces increasingly tight schedules, which necessitates that numerous construction tasks be completed within a short timeframe. As such, bricks with early strength can accelerate the construction process, enabling builders to meet the usage standards more efficiently and effectively, and ultimately improving progress and efficiency. The ability of bricks to maintain their structural integrity during transportation and installation, combined with their early strength, represents a significant advantage for builders seeking to complete projects on time and on budget.

Preparing the non-fired bricks could be a potential method to resource the waste mud. Compared with finished bricks in the market, non-fired bricks made of shield tunnel mud have significant economic advantages [7]. Firstly, the raw material of non-fired bricks is soil, which has a low production cost, and the production process does not require high-temperature firing, saving fuel and energy consumption and reducing environmental pollution [8]. Secondly, non-fired bricks have a short production cycle and high production efficiency, which can meet the urgent needs of construction projects [9]. In addition, due to the high strength and compressive performance of non-fired bricks made of shield tunnel mud, they can replace some traditional finished bricks in building construction, reducing the procurement cost of building materials [10].

Furthermore, the production of non-fired bricks can effectively reduce the depletion of natural resources caused by the extraction and processing of raw materials, as well as the release of pollutants generated during high-temperature firing [11]. In addition, the utilization of shield tunnel mud for non-fired brick production can reduce the disposal and treatment of tunnel mud, which is often a major challenge in tunnel construction projects. Therefore, non-fired bricks made of shield tunnel mud are not only economically advantageous but also environmentally friendly, making them a more sustainable option for building materials. It is worth noting that the use of non-fired bricks may require adjustments to construction practices, such as the use of specialized adhesives or mortar. However, the benefits in terms of cost savings and sustainability make it a worthwhile consideration for construction projects.

In this study, we explored the compressive strength of the prepared test bricks by screening the formula of the curing agent, changing the molding pressure, material moisture content, and curing agent dosage. This led to the identification of the optimal conditions for preparing the bricks. Subsequently, we analyzed the market economic benefits of the prepared bricks based on relevant market conditions. Specifically, we investigated factors such as the cost of production, the demand for bricks in the local market, and the competitiveness of our product compared to other similar products. The results indicated that the prepared bricks had a high potential for economic benefits and could be a promising product in the local market. Overall, this study provides valuable insights for optimizing the production process and marketing strategy of the bricks.

2 Materials and Method

2.1 Materials and Equipment

Waste mud was obtained from the construction site of zhijiang road in zhejiang province, China. The 525 Portland cement, 525 early-strength Portland cement, and GS soil hardening agent were all commercial grade for hardening mud as bricks. The standard cement mortar test box (HBY-30CA, Leiyun) was used for curing the bricks. The compressive strength testing machine (YES-300, Xinshiji) was used to determine the compressive strength of the bricks.

2.2 Curing experiment

2.2.1 Selection of curing agent formulations.

Three types of curing agent formulations were tested in three groups, with a designed dosage of 12%. Parallel samples were set up for each group. The bricks were made with a moisture content of 30% and 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 designed age was reached, and then tested for compressive strength.

2.2.2 Influence of molding pressure on compressive strength of bricks

Using a designed dosage of 12% for the curing agent, the bricks were divided into five groups with a moisture content of 30%. The molding pressures were 10 MPa, 20 MPa, 40 MPa, 60 MPa, and 80 MPa, respectively. Parallel samples were set up for each group. The bricks were placed in a standard curing box with constant temperature (20±1°C) and humidity (≥90%) until the designed age was reached, and then tested for compressive strength.

2.2.3 Influence of material moisture content on compressive strength of bricks

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

2.2.4 Influence of temperature on compressive strength of bricks.

Using a designed dosage of 12% for the curing agent, the bricks were molded with a moisture content of 30% 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 the designed age was reached.

2.2.5 Influence of curing agent dosage on compressive strength of bricks.

Three groups of mud with curing agent dosages of 12%, 15%, and 18% were prepared. Parallel samples were set up for each group. 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 (≥90%) until the designed age was reached. They were then tested for compressive strength.

2.2.6 Influence of adding skeletal on compressive strength of bricks

According to the design mix, 12% cement and the corresponding skeletal (sand) were added, with a controlled moisture content of 30% and molded at a pressure of 20 MPa. The masonry bricks were placed in a standard curing box with constant temperature (20±1°C) and humidity (≥90%) for the designated age before conducting compressive strength testing.

2.2.7 Influence of adding sieved aggregate on compressive strength of bricks.

An experimental investigation on the effect of different sieving stages of raw materials on compressive strength of bricks. According to the design of the hardening agent, 12% was added, and different stages of screened raw materials (first-stage bottom slag, second-stage bottom slag, mud cake) were mixed. Parallel samples were set up for each group of tests, molded at a pressure of 20 MPa, and placed in a standard curing box with constant temperature (20±1°C) and humidity (≥90%) for the designated age before conducting compressive strength testing.

3 Results and Discussion

3.1 The Composition and Properties of Waste Mud

Table 1. Grain proportion of waste mud

diameter /mm	＞0.25	0.15～0.25	0.075～0.15	0.045～0.075	＜0.045
proportion/%	8.2	5.09	84.12	1.46	1.16

The sand content of waste mud is 71.66%, and the grain proportion is shown in Table 1. According to the soil classification standard GBJ 145-90, the soil quality is fine sand.

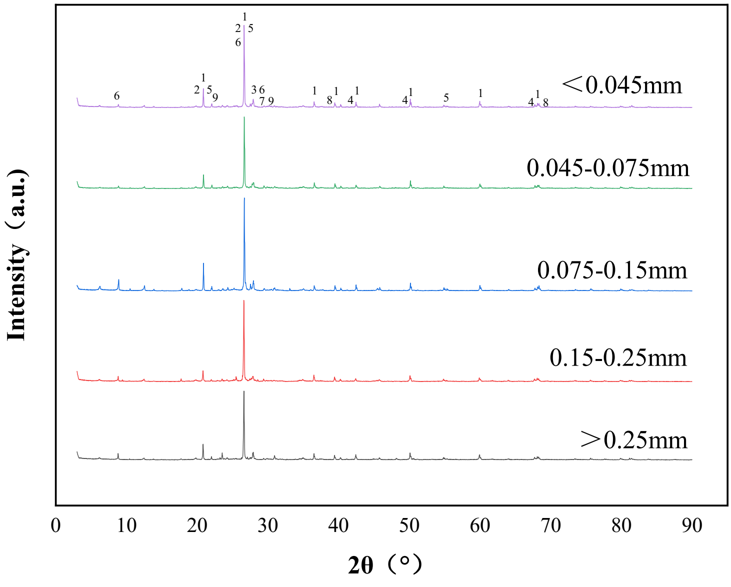

Fig. 1. X-Ray diffraction spectra of waste mud with different size distribution. (1-Quartz; 2-kaolin; 3-calcium feldspar; 4-calcitrate feldspar; 5-microplagioclase; 6-mica in ink jade; 7-magnesium silicate; 8-talc; 9-albite)

The XRD analyses of waste mud at various grain proportion are shown in Figure 1. The results indicate that the particle size distribution of the sediment is widely distributed and unevenly distributed, mainly in the range of 0.075 to 0.15 mm. XRD component analysis of the samples revealed that the main components are quartz and clay minerals (kaolinite and mica), with relatively high content [12].

3.2 Selection of optimal curing agents

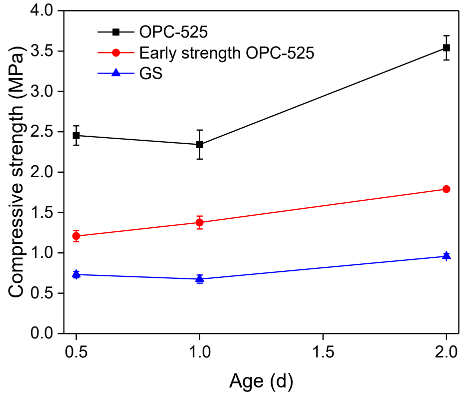

Fig. 2. Influence of various curing agents on compressive strength of bricks

According to the experimental results (Figure 2), compared with early-strength cement and GS soil hardening agent, the bricks cured with ordinary Portland cement (OPC) as the solidifying agent have the highest compressive strength, reaching 3.54 MPa at 2 days. The compressive strength of the bricks in the early-strength cement test group is close to the data of the OPC test group. Considering the cost-effectiveness (market price in 2021: early-strength cement is around 1500 yuan/ton, while OPC is around 400 yuan/ton in the off-season and around 600 yuan/ton in the peak season), OPC is preferred as the solidifying agent.

3.3 The effect of brickmaking pressure on compressive strength of brick

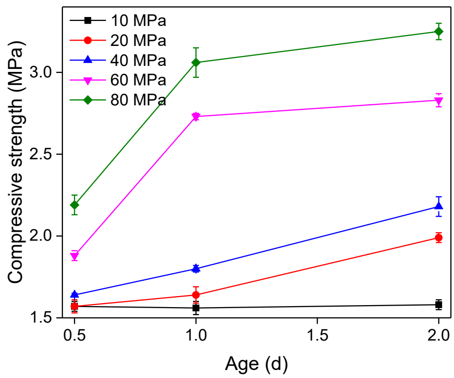

Fig. 3. Influence of molding pressure on compressive strength of bricks

According to the experimental results (Figure 3), it can be seen that the higher the pressure for making the mold, the higher the compressive strength of the masonry bricks. When the pressure for making the mold is 20 MPa, the compressive strength of the bricks after 2 days can reach about 2.2 MPa. The higher the pressure for making the mold, the more dry matter there is in the masonry bricks per unit volume, which can result in higher mechanical strength. Considering that the rated pressure of conventional brick-making machines is around 20 MPa, the subsequent experiments will control the pressure for making the mold at 20 MPa.

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

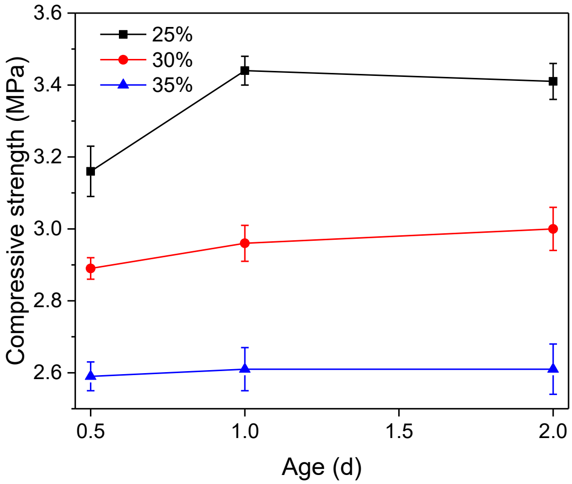

Fig. 4. Influence of waste mud moisture on compressive strength of bricks

Considering the fluctuation in the dewatering effect of the filter press on the slurry expected to be purchased at the construction site of zhijiang road project, this experiment simulates the moisture content of the mud cake under actual working conditions (fluctuating within the range of 25-35%) and conducts compressive strength tests on the prepared bricks with different moisture contents. The experimental results (Figure 4) show that the higher the moisture content of the material, the lower the compressive strength of the cured bricks. The lower the moisture content, the higher the content of dry matter in the unit volume of the brick, thus forming a higher mechanical strength. At the same time, the lower the moisture content, the shorter the time it takes to form the mechanical strength of the brick. After a maintenance period of 2 days, the compressive strength of bricks maintained at a low temperature reached about 1.63 MPa, while that of bricks maintained at room temperature reached about 1.85 MPa.

3.5 The effect of maintenance temperature on compressive strength of brick

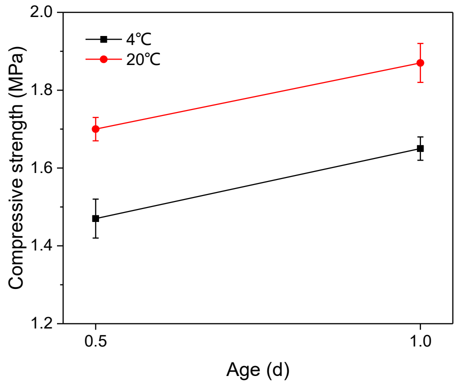

Fig. 5. Influence of maintenance temperature on compressive strength of bricks

In order to investigate the impact of outdoor maintenance environment during winter on the mechanical strength of masonry bricks, this experiment conducted compressive strength tests on bricks prepared under different maintenance temperatures. Through the test results (Figure 5), it was found that low temperatures had little effect on the early compressive strength of masonry bricks. The compressive strength of bricks maintained at a low temperature of 4°C was only about 0.20 MPa lower than that of the group tested at room temperature (20°C). After a maintenance period of 1 day, the compressive strength of bricks maintained at a low temperature reached about 1.63 MPa, while that of bricks maintained at room temperature reached about 1.85 MPa.

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

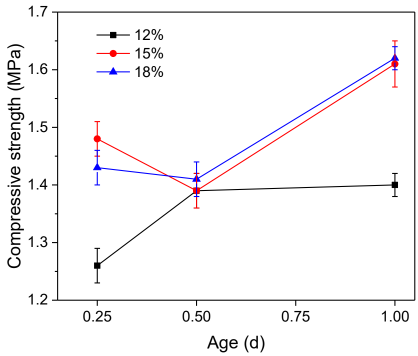

Fig. 6. Influence of curing agent dosage on compressive strength of bricks

Through the experimental results (Figure 6), it was found that increasing the dosage of curing agent (525 cement) can help improve the compressive strength of the masonry bricks. After a curing period of one day, the compressive strength of the masonry bricks in the 12% curing agent dosage test group can reach 1.30 MPa, while the compressive strength of the masonry bricks in the 18% curing agent dosage test group can reach 1.60 MPa.

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

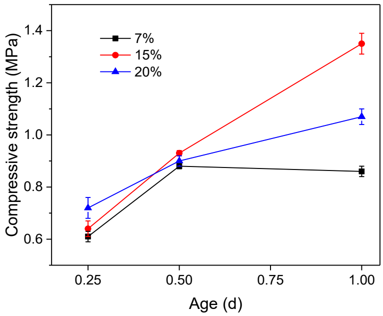

Fig. 7. Influence of skeletal material dosage on compressive strength of bricks

Through experimental results (Figure 7), it was found that the addition of aggregate can effectively improve the compressive strength of the bricks. The mechanical strength of the bricks in the test group with a sand content of 15% reached its highest value. This was particularly evident within a short period of 1 day. After being cured for 24 hours, the compressive strength of the bricks with a sand content of 15% was 1.35 MPa.

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

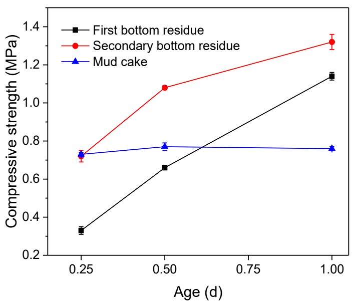

Fig. 8. Influence of waste mud from different sieving process on compressive strength of bricks

Based on the experimental results (Figure 8), it was found that the bricks prepared with secondary bottom residue had the highest compressive strength. After a short-term curing of 24 hours, the compressive strength could reach 1.32 MPa, and after a curing period of 24 days, the compressive strength could reach 2.04 MPa. In contrast, the compressive strength of bricks prepared with primary bottom residue was lower, with a value of only 1.05 MPa after 24 days of curing. Therefore, it can be inferred that the particle size of the raw materials has a significant impact on the compressive strength of the bricks.

3.9 Economical analysis

The production cost of bricks is a crucial factor in determining the profitability of any brick-making operation. The cost of cement, which is a primary component of brick production, can significantly impact the cost per ton of bricks. Therefore, it is important to carefully evaluate the costs of all raw materials and other expenses to accurately calculate the cost per ton of bricks. The production cost per ton of bricks can be expressed as: 1.43 tons of raw materials per ton of bricks multiplied by the cost of cement per ton of raw materials, plus other costs, which yields an approximate value of 96.91 RMB per ton of bricks.

Additionally, the value generated from processing tunneling mud can have a significant impact on the profitability of a brick-making operation. The conversion rate from ton of bricks to ton of shield tunneling mud must be considered when evaluating the economic benefits of processing tunneling mud. The value generated from processing 1.26 tons of shield tunneling mud is calculated as follows: the value per ton of bricks (282.75 RMB/ton) multiplied by the conversion rate from ton of bricks to ton of shield tunneling mud (1.26), minus the production cost of 1.26 tons of bricks (96.91 RMB/ton), which results in an approximate value of 171.45 RMB/ton bricks.

It is also important to note that the economic benefits generated from processing tunneling mud can vary depending on a variety of factors. For instance, fluctuations in the cost of raw materials and other expenses can impact the profit margin of the process. Therefore, it is important to continually evaluate and adjust production processes to maximize profitability and minimize costs. The economic benefits generated from processing 1.26 tons of shield tunneling mud range from 142 to 169 RMB, indicating a profit margin of 11.5% to 14.2% for the process.

4 Conclusion

Soil quality of waste mud is fine sand with a wide particle size distribution mainly in the range of 0.075 to 0.15 mm. XRD component analysis indicates that the main components are quartz and clay minerals. The optimal curing agents -Portland cement (OPC) is the preferred solidifying agent considering its highest compressive strength of 3.54 MPa at 2 days and cost-effectiveness. The effect of brickmaking pressure on compressive strength indicating that higher mold-making pressure results in higher compressive strength of the masonry bricks, and the subsequent experiments will control the pressure for making the mold at 20 MPa. Then the higher moisture content leads to lower compressive strength of the cured bricks, and the lower the moisture content, the shorter the time it takes to form the mechanical strength of the brick. Section 3.5 investigates the effect of maintenance temperature on compressive strength, showing that low temperatures have little effect on the early compressive strength of masonry bricks. Thus, the process realizes the reduction and resource of waste mud from slurry shield tunnel.

Acknowledgement

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