Research and application of cave slag tailings in concrete

Qi Rao*, Hengchun Zhang, Rui Wan, Shuiping Xi, Dianxing Wu and Chunyang Luo

China Construction Ready Mixed Concrete Fujian Co., Ltd, Fuzhou, China

*Corresponding author e-mail: 663948548@qq.com

Abstract. This article starts with the characteristics of cave slag tailings, proposes to optimize the quality of the concrete production process and product structure by improving the composition of concrete fine aggregates, and conducts research on the key technologies of the application of cave slag tailings to concrete. Concrete quality and economic cost are the basic frameworks, and the feasibility of using cave slag tailings is comprehensively analyzed. It has been verified by experiments that the application of cave slag tailings can greatly improve the stability of concrete production process, reduce concrete structural defects and quality disputes caused by process control, and can significantly reduce the cost of single main material of concrete and bring good Economic benefits. At present, the slag tailings of the cave have been widely used in the resettlement houses of Houyu, Minhou, the MIXC# building, TA# building and its basement of the fourth phase of Fuzhou China Resources Vientiane City, and all performances have reached the engineering design requirements.

1. Introduction

With the rapid development of my country's economy in recent years, investment in transportation construction has increased year by year. Resource conservation, green production, and sustainable development are important issues facing environmental protection in construction projects. The spoil generated by highway engineering projects is mainly tunnel slag, which accounts for 46% of the total amount of waste soil and spoil. If it is directly discarded, it will cause great damage to the environment, such as blocking rivers and occupying arable land[1]. As one of the main raw materials in ready-mixed concrete, Manufactured sand has unstable quality, which affects the quality of ready-mixed concrete. With the rapid advancement of my country's infrastructure construction, the demand for sand, which is the main construction raw material, is huge, and the country's natural river sand resources are nearly exhausted, which has caused the price of sand to soar. Cave slag tailings are derived from the process of crushing cave slag into gravel. Compared with Manufactured sand, its fineness modulus is stable and the advantages of low water content are more conducive to quality control in the concrete production process.

At present, domestic cave slag is mainly used for backfilling, and a few are used to produce concrete raw materials such as sand and gravel, and the overall utilization rate is not high. Wu et al. [2] used a lot of tunnel slag on Xinfu Expressway. It is mainly used for embankment filling, Manufactured sand processing, gravel processing, etc. A total of 1.624 million cubic meters of tunnel slag was used, with a utilization rate of 66.5%, and estimated cost savings of more than 48.9 million yuan. Tian et al. [3] tested the tunnel slag during the construction of the A9 contract section of the Changde-Jishou...
Expressway in Hunan. The analysis shows that all indexes of the filler meet the requirements, and it is an ideal subgrade filler. Fan et al. [4] also discussed the treatment methods of tunnel slag in different projects and the protection measures of tunnel slag yard. The results show that the application of tunnel slag not only reduces the permanent land occupation of the project, but also increases revenue. Italy Politecnico believes that tunnel slag can be used in different projects through correct treatment, and it will also bring good environmental and economic benefits [5]. Rossana et al. [6] believe that the construction of 300km railway tunnels and 150km road tunnels in Italy will produce a large amount of cavernous slag, which will have a great impact on the environment. If various technical methods are used in the project to combine cave slag with cement or asphalt, huge economic benefits will be produced. From the perspective of utilization and research of cave slag at home and abroad, it is mainly used in the use of backfill and the experimental technology demonstration of raw materials in concrete. At present, the utilization of tunnel slag is still in its infancy. Although all localities have gradually realized the importance of the use of cave slag, the overall situation is not systematic and comprehensive.

Based on this, this thesis conducts a comprehensive study and analysis of various physical properties and index parameters of cave slag tailings, and compares them with normal gravel. Manufactured sand, masters its basic characteristics, and formulates an acceptance system. Scientifically carry out the design and adjustment of the mix ratio, understand the performance of its various properties in the concrete through trial mix and pilot test, grasp its changing law, and formulate the corresponding control plan. Finally, it is gradually extended to actual production, and the mechanical characteristics and durability indicators of the physical structure are tracked to consolidate the research results. It aims to form a systematic feasibility analysis of the use of cave slag tailings and technical solutions for finished products, so as to provide comprehensive scientific technical support for the reasonable and efficient utilization of cave slag tails.

2. Feasibility analysis of tunnel slag utilization

The use of cave slag tailings is of great significance in terms of environmental protection and economic benefits. However, considering the difference in quality of cave slag tailings, not all excavated cave slag can be processed and utilized, and some cave slag may contain parent rock Severe weathering, low strength, etc. cannot meet the quality requirements for preparing sand and gravel; some tunnel slag may be due to its processing cost and other costs higher than its economic benefits, so whether the application of slag tailings is finally feasible depends on Comprehensive analysis of the surrounding rock condition, quality, cost difference of regional Manufactured sand, geographical location and road transportation of the tunnel, so the three indicators are used as the basic framework to construct a feasibility analysis system for the application of cave slag tailings, as shown in the figure below 1 shows:

![Figure 1: Feasibility analysis system for utilization of cave slag tailings](image-url)
3. Research on Key Techniques of Quality Control of Mixing Cave Slag Tailings into Concrete

3.1. Optimization of fine sand dosage

The reduction in the amount of fine sand can greatly reduce the shrinkage and cracks of the concrete. In the production process, the high viscosity of concrete caused by fine sand is not conducive to pumping. At the same time, the price of fine sand in Fuzhou has always been higher than that of Manufactured sand, and the reduction of fine sand also helps companies reduce costs and increase efficiency.

The mixing ratio of slump, expansion degree and workability consistent between the same label is used as the basic comparison condition.

Table 1. Test mix ratio of concrete

| Sample | Grade | C | F | K | S1 | S2 | S3 | G | W | A | H0/L0 (mm) | Performance |
|--------|-------|---|---|---|----|----|----|---|---|---|-------------|-------------|
| S1     | C30   | 19/5 | 65 | 80 | 320 | 54 | 0 | 98 | 165 | 1.2 | 230/630 | Well        |
| S2     | C30   | 19/5 | 65 | 80 | 240 | 62 | 0 | 98 | 168 | 1.2 | 230/630 | Well        |
| S3     | C40   | 23/0 | 75 | 100 | 300 | 52 | 0 | 97 | 155 | 1.3 | 240/680 | Well        |
| S4     | C40   | 23/0 | 75 | 100 | 200 | 62 | 0 | 97 | 157 | 1.3 | 240/680 | Well        |
| S5     | C50   | 31/5 | 65 | 100 | 230 | 50 | 0 | 99 | 150 | 1.4 | 260/680 | Well        |
| S6     | C50   | 31/5 | 65 | 100 | 100 | 63 | 0 | 99 | 152 | 1.3 | 260/680 | Well        |

Note: Fine sand = S1, Manufactured sand = S2, Cave slag tailings = S3, Gravel = G, Water = W, Additive dosage (%) = A.

It can be seen from Table 1 that because the fineness modulus of cave slag tailings is lower than that of Manufactured sand, and the content of stone powder is higher, the amount of fine sand in cave slag tailings will be lower than that of Manufactured sand under the same trial configuration state, and as the number increases, The amount of fine sand for unilateral concrete can be reduced by 80kg/m³~130kg/m³.

3.2. Design of Mixture Ratio of Cave Slag Concrete

The cave slag tailings have changed the total amount of powdery materials in the concrete due to the presence of stone powder similar to the glue particles. The cave slag concrete has been transformed into a glue system of cement + fly ash + slag powder + stone powder. Therefore, cave slag tailings are more suitable for use in large-volume concrete. Stone powder particles can effectively compensate for the poor workability of large-volume concrete due to the low powder consumption without significantly increasing the heat of hydration. Due to the high content of stone powder, the specific surface area of the concrete powder system is significantly increased. Therefore, when selecting the water consumption, the water consumption increase coefficient K should be set on the basis of the ordinary concrete mix design, and K is proposed to be 1.03. Furthermore, due to the low fineness modulus of cave slag tailings, the sand ratio should be appropriately lowered when selecting the sand ratio, and the sand ratio increase coefficient f should be set.

Table 2 shows the mixing ratio of cave slag tailing concrete and Manufactured sand concrete. It can be seen that the hydration heat of cave slag tailing coagulation is lower, and more water and higher admixtures are required under the same conditions. The sand rate and the amount of fine sand are lower.
Table 2. Mix ratio of cave slag concrete

| Grade       | C   | F   | K   | S2/3 | S1  | G   | W   | A       |
|-------------|-----|-----|-----|------|-----|-----|-----|---------|
| Standard concrete mixtures | C30 | 203 | 80  | 70   | 500 | 350 | 980 | 165  | 1.30%  |
| Cave slag concrete mixtures | C30 | 203 | 80  | 70   | 570 | 250 | 1010 | 168  | 1.35%  |

Note: Fine sand = S1, Manufactured sand = S2, Cave slag tailings = S3, Gravel = G, Water = W, Additive dosage (%) = A.

3.3 Influence of stone powder content of cave slag tailings on performance of concrete mixture

Due to the instability of cave slag tailings, the content of stone powder fluctuates greatly, and the content of stone powder will affect the water consumption of concrete, the amount of admixtures in the concrete mixture, and the slump loss over time. Table 3 shows the influence of stone powder content in cave slag tailings on concrete performance.

Table 3. Influence of stone powder content in cave slag tailings on concrete performance

| Sample | CS | W | A     | H0/L0 (mm) | performance | H1h/L1h (mm) | performance | H2h/L2h (mm) | performance |
|--------|----|---|-------|------------|-------------|--------------|-------------|--------------|-------------|
| S1     | 9% | 16/8 | 1.32  | 235/62/0   | Well        | 210/570 Well | 180/510 Well |
| S2     | 11% | 17/0 | 1.35  | 235/62/0   | Well        | 215/570 Well | 180/500 Well |
| S3     | 13% | 17/2 | 1.38  | 235/62/0   | Well        | 210/560 Well | 185/490 Well |
| S4     | 15% | 17/4 | 1.41  | 235/62/0   | Well        | 210/560 Well | 180/490 Well |
| S5     | 17% | 17/7 | 1.45  | 235/62/0   | Well        | 200/550 Well | 160/450 Well |

Note: Stone powder content = CS, Water = W, Additive dosage (%) = A.

It can be seen from Table 3 that with the initial slump consistent as the basic condition, with the increase of the stone powder content in the concrete mixture, the admixture and water consumption increase, but the fluctuation is small; the slump loss over time aspect: As the content of stone powder increases, the slump loss will increase over time. It can be seen that when the content of stone powder in the cave slag tailings is within 15%, the slump loss over time is controllable, and the overall workability is basically satisfied. Site pouring requirements.

3.4 Influence of cave slag tailings on concrete strength

The strength performance of cave slag tailings in concrete is also a crucial link in the availability analysis of cave slag tailings. The cave slag tailings are in accordance with the artificial sand in JGJ52-2006 "Standard for Sand and Stone Quality and Inspection Methods for Ordinary Concrete" Testing is carried out according to the experimental standard, and all the testing indicators meet the requirements of the standard except for the content of stone powder. Table 4 shows the influence of stone powder content in cave slag tailings on concrete performance.
Table 4: Influence of stone powder content in cave slag tailings on concrete performance

| Sample | CS | A  | H0/L0 (mm) | H1h/L1h (mm) | H2h/L2h (mm) | Compressive strength (MPa) |
|--------|----|----|------------|--------------|--------------|---------------------------|
|        |    |    |            |              |              | 7d | 28d |
| S1     | 9% | 1.32 | 235/620 | 210/570 | 180/510 | 28.4 | 39.3 |
| S2     | 11%| 1.35 | 235/620 | 215/570 | 180/500 | 28.7 | 40.2 |
| S3     | 13%| 1.38 | 235/620 | 210/560 | 185/490 | 29.3 | 41.8 |
| S4     | 15%| 1.41 | 235/620 | 210/560 | 180/500 | 29.9 | 43.1 |
| S5     | 17%| 1.45 | 235/620 | 200/550 | 160/450 | 27.8 | 36.9 |

Note: Stone powder content = CS, Additive dosage (%) = A.

It can be seen from Table 4 that as the content of stone powder increases, there should be a benign development in the compressive strength of concrete. However, when the content of stone powder in the tailings of the cave is higher than 17%, the compressive strength decreases, mainly because of the stone powder content. The increase of the content is to ensure the change of the hard water demand caused by the initial workability; further according to the experimental analysis, it is found that the residual stone powder below 150μm is used, according to GB/T1596-2017 "Pulverized coal used in cement and concrete" The "ash" standard requires a water demand ratio test for the residual sand from the screen, and it is found that the residual sand meets the requirements of the standard for the water demand ratio of class F II fly ash, and the stone powder in the tailings of the cave is with the class F II fly ash. Basically in a level of fineness, its physical properties are close to fly ash, but it does not have the pozzolanic effect of fly ash. Therefore, we can regard cave slag tailings as an inert cementing material. As the content increases, the inert cementing material in the concrete will also increase. In order to ensure the initial slump and workability, the water-binder ratio increases and the concrete strength is reduced.

3.5. Application of cave slag tailings in mass concrete

Because there are more stone powders similar to rubber particles in the tailings of the cavernous slag, this part of the stone powder has certain activity, and the addition of the stone powder improves the disadvantages of multiple edges and poor gradation between the aggregates, and makes the aggregates more stable. As the bulk density increases, the stone powder particles can also fill the pores in the concrete and increase the density of the interface transition zone. Therefore, in theory, it can replace part of the cementing material in the same amount. This can effectively reduce the strength of the concrete without significant changes. The heat of hydration, but how to set the optimal replacement amount of stone powder particles needs further study. Table 5 shows the effect of stone powder equivalent replacement of cementitious materials on concrete performance.

Table 5: The influence of stone powder equivalent replacing cementitious material on concrete performance

| Sample | C  | F  | K  | CS | Compressive strength (MPa) |
|--------|----|----|----|----|---------------------------|
|        |    |    |    |    | 7d | 28d | 60d |
| S1     | 203| 80 | 70 | 0  | 28.4 | 39.3 | 51.2 |
| S2     | 198| 80 | 70 | 5  | 27.8 | 39.1 | 50.2 |
| S3     | 193| 80 | 70 | 10 | 27.1 | 39.4 | 49.4 |
| S4     | 188| 80 | 70 | 15 | 26.5 | 38.7 | 49.7 |
| S5     | 183| 80 | 70 | 20 | 25.5 | 36.9 | 47.3 |
| S6     | 203| 75 | 70 | 5  | 28.2 | 39.5 | 50.8 |
| S7     | 203| 70 | 70 | 10 | 27.5 | 39.3 | 49.6 |
| S8     | 203| 65 | 70 | 15 | 27.4 | 38.4 | 50.1 |
| S9     | 203| 60 | 70 | 20 | 26.1 | 37.8 | 48.3 |
| S10    | 203| 80 | 65 | 5  | 29.3 | 40.2 | 52.2 |
| S11    | 203| 80 | 60 | 10 | 28.1 | 40.3 | 50.3 |
| S12    | 203| 80 | 55 | 15 | 27.3 | 39.4 | 48.9 |
| S13    | 203| 80 | 50 | 20 | 26.5 | 37.1 | 47.5 |

Note: Stone powder content = CS.
It can be seen from Table 5 that when the stone powder substitute powder is within 15kg, the 28d trial concrete compressive strength meets the requirements for the compounding strength in the JGJ55-2011 "Common Concrete Mixture Design Regulations". The main principle is that a part of the stone powder particles are in the cement In the early hydration process, it acts as a nucleus for the formation of Ca(OH)2 and CSH, accelerating the hydration of clinker minerals, and the fine particles of cave slag tailings stone powder can also hydrate with C3A to form hydrated aluminum carbonate Calcium is conducive to the early strength development. When the replacement amount of stone powder reaches 20kg, the stone powder in the tailings of cave slag does not have a pozzolanic effect similar to that of fly ash, and there is no gain in the later strength growth, but it affects the concrete of cave slag tailings. Intensity development.

4. Economic benefit
In 2020, the Fujian Division's Minhou Plant will achieve stable production of cave slag concrete. It will use 4,5553.1 tons of cave slag tailings throughout the year, realizing an additional profit of 686,300 yuan, and basically achieving good economic benefits.

5. Traffic Analysis
The cave slag comes from the construction of the tunnel, and the traffic and terrain conditions around the tunnel determine the utilization rate of this cave slag processing. The current cave slag tailings come from the construction site of the Wusi North Road tunnel. There is a partner company's sand and gravel near the Wusi North area. The processing plant has good transportation conditions and meets the needs of materials entering the plant. The transportation cost is consistent with that of Manufactured sand in the region.

6. Application of cave slag tailings in engineering
Fuzhou Minhou County Rongji Houyu Jiayuan Project, Fuzhou China Resources Vientiane City Phase IV MIXC# Building, TA# Building and its basement projects, C15-C50 labeled concrete all involve the production of cave slag tailings, and construction during the pouring process The performance is good. After one hour, the flow performance and later strength meet the design requirements.

7. Conclusion
In this paper, the basic framework and ideas of the feasibility analysis system for the utilization of cave slag tailings are constructed, and verified through experiments and practical applications. The various physical properties and index parameters of the tailings were studied and analyzed, and compared with normal gravel Manufactured sand to master its basic characteristics. Scientifically carry out mix design and adjustment, experimental trial and pilot test, understand the performance and change law of its various properties in concrete, and finally form a set of new technology for research and application of cave slag tailing concrete. This technology helps to improve the environmental damage caused by the secondary crushing of cave slag and improve resource utilization. At the same time, alleviate the tight situation of sand use by concrete enterprises and improve the quality stability of sand. In addition, it will reduce the dependence on fine sand and reduce the risk of using sand. Can effectively reduce production costs, improve product profitability and market competitiveness.

8. Acknowledgments
This work was financially supported by China Construction Ready Mixed Concrete Co., Ltd fund (ZJXJ-ZH-2020-08). The supports are gratefully acknowledged. Any opinions, findings, conclusions, and recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the sponsors.

References
[1] T Deng. Research on the application technology of Manufactured sand and Manufactured sand concrete from tunnel slag [D]. Wuhan University of Technology, 2012.
[2] Z J Wu, R F Tian, X W Zhao, et al. Comprehensive application of tunnel slag in Xinfu Expressway[J]. Highway Transportation Science and Technology (Applied Technology Edition), 2011, 000(004): 68-69.

[3] H X Tian. Talking about the construction experience of using tunnel waste slag as the filling material on the highway subgrade [J]. Henan Building Materials, 2008, 000(005): 50-51.

[4] G M Fan, S F Li, C J Chen. Discussion on the treatment of spoil of highway engineering in Zhejiang mountainous and hilly area[J]. China Soil and Water Conservation Science, 2007(05):94-97.

[5] Bellopede R, Marini P. Aggregates from tunnel muck treatments. Properties and uses[J]. Physicochemical Problems of Mineral Processing, 2011, 47(47):259-266.

[6] Rossana B, Fabrizio B, Pierpaolo O, et al. Main Aspects of Tunnel Muck Recycling[J]. American Journal of Environmental Sciences, 2011, 7(4):338-347.