A study on the mechanical properties of cement soil added with ferronickel slag

WeiFan, Feng Chen
College of Engineering, Fujian Jiangxia University, Fuzhou, Fujian Province, P. R. China
Fw408@163.com, 8303433@qq.com

Abstract. Unconfined compressive strength test was employed hereby to study the effect of ferronickel slag content and mineral powder content on strength performance of cement soil. In the experiment, 0%, 10%, 20%, 30% and 40% ferronickel slag were added into the cement soil, respectively, to figure out the comparatively better content of ferronickel slag was 20%. The experiment results also indicate the addition of ferronickel slag also significantly affected the early strength of cement soil, but as the time proceeded, the strength of cement soil added with ferronickel slag fell less quickly as before.

1. Introduction
As a kind of building material, cement soil has displayed significant effect in engineering construction with its outstanding performance. How to improve the performance of cement soil but cut down the engineering cost has aroused wide attention. J. T. Huang conducted an unconfined compressive strength test on cement soil samples to discuss the effect of cement content and dry unit weight on the strength of cement soil. Shenbaga R. Kaniraj et al. established functional relations among different variables. By studying the cement soil with triaxial test, Mostafa A. Ismail et al. determined the effect of cement species on its strength. S. Kolias et al. investigated the effect of coal ash on the cement soil strength. In view of the studies above, we can find it becomes an increasingly important tendency to find a mineral admixture saving resources and cutting cost for the cement soil in engineering work. Therefore, this paper proposes to substituting the cement in cement soil with ferronickel slag in order to recycle the resources and turn waste to treasure. Moreover, being cheaper than cement in cost, the ferronickel slag can also help to reduce the engineering cost, yield higher economic benefits, and thus has great potential of promotion.

2. Experiment
In the experiment, raw materials included mucky soil within the subway foundation pit sampled at a depth of 20-21m, P•O42.5 ordinary Portland cement with compressive strength being 25.7MPa and 46.3MPa on 3d and 7d, respectively, and admixture-ferronickel slag. This paper adopted unconfined compressive strength test to determine the strength of cement soil added with ferronickel slag, because this test featured accurate result, simple operation, and convenient application and it is the most widely used method in mechanical studies. The experimental instrument was MTS Landmark 370.50 fatigue machine, and specimens were test cubes measuring 70.7 mm×70.7 mm× 70.7 mm. The experiment was provided with two variables, namely ferronickel slag content and mineral powder content. Altogether nine groups were set within the experiment for comparative analysis, and corresponding
mixing ratios were listed in Table 1. Each mixing ratio was tested with three specimens to take the average strength.

Table 1. Experimental cement-soil mixture ratio.

| Number | Cement ratio (%) | W/C | Ferronickel slag (%) |
|--------|------------------|-----|-----------------------|
| A      | 15               | 0.5 | 0                     |
| B      | 10               |     | 10                    |
| C      | 20               |     | 20                    |
| D      | 30               |     | 30                    |
| E      | 40               |     | 40                    |

3. Analysis of experimental results

3.1 Experimental results

Unconfined compressive strengths of cement soil added with different ratios of ferronickel slag on different days were determined on the basis of experimental data processing, showed in Figure 1 and Table 2. With the Group A in which mixing ratio of ferronickel slag was 0% as the reference group, a comparative analysis was performed on the groups of different mixing ratios of ferronickel slag and ages so as to figure out the drop rate of unconfined compressive strength in all the groups from A to E. For groups with mixed additionally with mineral powder, Group C was set as the reference one. The unconfined compressive strength growth rates of groups C-1 to C-4 were computed relative to reference group C. Details are provided in Table 2.

Table 2. Unconfined compressive strength rate of change

| Number | A     | B     | C     | D     | E     |
|--------|-------|-------|-------|-------|-------|
| 7d     | 1.08  | 0.87  | 0.80  | 0.57  | 0.44  |
| 28d    | 1.75  | 1.69  | 1.55  | 1.40  | 1.02  |
| 60d    | 1.95  | 2.00  | 1.82  | 1.73  | 1.44  |
| 90d    | 2.40  | 2.60  | 2.32  | 2.14  | 1.86  |
| 7d     |       |       |       |       | 20.4  |
| 28d    |       |       |       |       | 12.0  |
| 60d    |       |       |       |       | 7.1   |
| 90d    |       |       |       |       | 3.3   |

3.2 Effect of ferronickel slag on mechanical performance

Figure 1 Relationship between the content and the strength decreasing rate
Based on experimental data as revealed in Table 2, curves of relation between ferronickel slag content and cement soil’s unconfined compressive strength test were plotted. The curves can demonstrate the effect of ferronickel slag content on cement soil strength in a more direct way. As shown in Fig. 2, the unconfined compressive strength falling rate curve on 7d was relatively farther from that on 28d, 60d and 90d with a steeper inclination. The curves on 28d, 60d and 90d are quite close to each other and their inclinations become smoother. Detailed analysis is as follows:

(1) The strength dropping rate of cement soil added with ferronickel slag is far higher on 7d than on other ages. When ferronickel slag content was 10%, 20%, 30% and 40%, respectively, the strength was 20.4%, 26.9%, 47.2% and 60.2% lower than that of reference group A. This is especially apparent for the groups with ferronickel slag content being 30% and 40%, respectively, which show a significant decrease in the performance or strength of cement soil in early period. It thus makes clear that the role played by ferronickel slag on 7d is far less significant that that played by the substituting cement in the cement soil so that cement soil mixed with ferronickel slag undergoes a more significant decrease in the cement soil strength. This also means the ferronickel slag is less active on 7d and acts insignificantly on the strength of cement soil.

(2) As shown in Fig. 2, the strength dropping rate of cement mixed with different ratios of ferronickel slag on 28d is evidently lower than that on 7d. When ferronickel slag content is 10%, the strength drops by only 3.4% when compared with the reference group. When the ferronickel slag content is below 30%, the strength dropping rate of cement soil mixed with ferronickel slag is all below 20%. It indicates the ferronickel slag within the cement soil produces a more significant effect on the strength of cement soil on 28d than on 7d, and the activity of ferronickel slag gets slowly.
excited so that a great increase is spotted on the strength of cement soil mixed with ferronickel slag when compared with that on 7d.

(3) The strength dropping rates of cement soil mixed with different contents of ferronickel slag on 60d and 90d are quite close to each other, and corresponding curves show same tendency. It is noteworthy that when ferronickel slag content is 10%, the unconfined compressive strength already exceeds the strength of reference group A by being 2.0MPa and 2.6MPa, respectively (which is 0.05MPa and 0.2MPa higher at a dropping rate of -2.5% and -8.3%). When the content is 20%, the cement soil strength on 60d and 90d are 1.82MPa and 2.32MPa, respectively, being only 0.13MPa and 0.08MPa lower than that of reference group A at a dropping rate of 7.15% and 3.35% (below 10% in both cases). The strength dropping rate is only 3.35% on 90d. But when the content is higher than 20%, the strength dropping rate is increasingly larger on both 60d and 90d and more vastly different from that of reference group A so that the strength conditions can no longer meet the requirements set in the experiment.

The analysis above suggests ferronickel slag is a sort of mineral admixture with low activity. When its content is high (over 20%), it can’t supplant cement in contributing to the strength of cement soil so that cement soil reveals great decrease in its strength on different days and fails to meet the engineering requirements. However, when the content of ferronickel slag is 10%, the cement soil strength is a little bit higher than that with content being 20%. After weighing economic factors and utilization rate of ferronickel slag, the following conclusion is drawn: when ferronickel slag is added alone, 20% would be a preferred mixing ratio.

4. Conclusions
The addition of ferronickel slag can greatly reduce the strength of cement soil. However, as the time goes, the strength dropping rate is lower and lower. It indicates as a lowly active mineral admixture, the ferronickel slag can’t function until 28d later and its strengthening effect on cement soil strength can well last even on 90d. According to the experimental results, when ferronickel slag is added alone, 20% would be preferred as the mixing ratio.

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