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# Backfilling performance of mixtures of dredged river sediment and iron tailing slag stabilized by calcium carbide slag in mine goaf

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## HIGHLIGHTS

- Recycling of wastes as backfilling materials in mine goaf is an optional way.
- CCS replacement of cement can elevate the slump value of DRS and ITS mixture.
- Optimal proportion among DRS, ITS, OPC and CCS is 60:40:16:4 in mass in this case.
- An updated expression to predict the strength is proposed just with two variables.

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## ABSTRACT

Re-utilization of industrial wastes or by-products in construction, including dredged river sediments (DRS), iron tailing slag (ITS) and calcium carbide slag (CCS) etc., can reduce the construction cost, decrease the storage requirement and also be of great benefit to the environment. In this research, the aforementioned wastes (*i.e.*, DRS, ITS and CCS) were synthetically recycled and used as the backfilling materials in the mine goaf to solve the problem of subsidence. Systematic laboratory experiments were conducted to ensure that these recycled materials can fulfill the requirement on the slump value and unconfined compressive strength after 7-day's curing. The results show that despite that Ordinary Portland cement (OPC) suppresses the slump value, CCS elevates the flowability, and then the maximal flowability is achieved when the mass ratio of DRS to ITS was 70:30 with a cement content of 16.7%. ITS addition into DRS upgrades the strength of the mixtures of DRS and ITS stabilized by OPC and CCS for the skeleton effect and water content reduction. The optimal proportion between DRS, ITS, OPC and CCS in this case is 60:40:16:4 in mass, with a slump value of about 160, and unconfined compression strength after 7-day's curing about 2.8 MPa. At last, a simple expression to predict the strength of the backfilling materials was proposed referring the gel-space theory and the concept of volumetric solid content, where just two variables (*i.e.*, the binder content and the volumetric solid content) can characterize this complex matrix.

## 1. Introduction

Large amounts of dredged river sediments (DRS) are artificially generated annually, and this volume reached more than 12 billion m$^3$ in China at the end of 2012 [1]. Furthermore, the amount of this waste is still expanded rapidly due to urbanization. The attention on the recycling use of dredged sediments (DRS), including its modification by the stabilization/incineration to fabricate the low-strength materials (including bricks, ceramic) and the improvement by vacuum preloading to form the in-situ foundations, is popular [2–10]. Since these approaches can only make use of very limited volume of DRS, many researchers suggested that it can be employed as a backfilling material for Karst cave or mine goaf. To fulfil the engineering requirement, the DRS with high water content and high fine grain content is usually stabilized by the cement and lime [11,12]. Note that since the industrial by-products such as fly ash, cement kiln dust (CKD) and calcium carbide slag (CCS)/calcium carbide residue (CCR) also are alkaline materials or pozzolanic materials which can produce a

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cementation, they are more and more adopted to replace the cement or lime in the past decades to reduce the construction cost and restrain $CO_2$ emission [12–14].

DRS feature high water content and fine particle fraction. Therefore adding coarse particles (such as sands) into the DRS is also an optional method to improve its engineering behavior [3,15,16]. A mining by-product after grinding, the iron tailing slag (ITS), can be used to replace sand because it is similar with sands in terms of particle size distribution and primary quart mineral. Such a reutilization of the ITS can also reduce the amount of the iron tailings and save the construction cost [17,18].

For environmental protection and sustainable resources, an innovative material of DRS stabilized by the industrial by-products to realize the recycling application in geo-infrastructure is encouraged. In this investigation, the attempt of the recycling wastes of local materials (including DRS, ITS and CCS) in Anhui Province China, is performed to generate the backfilling materials to stuff the local mine goaf for the subsidence controlling. To implement this objective, the engineering properties of the DRS and ITS mixture modified by CCS and OPC were systematically investigated to achieve the optimal proportion. Hereafter, the strength prediction method of the stabilized DRS was discussed.

## 2. Materials and methods

### 2.1. Materials

The DRS with a high initial moisture content and the ITS in the form of dry power were collected from HuangBei Lake and Longqiao Iron Mine Company, respectively, both which are located in Lujiang county, Anhui, China (Fig. 1). The photos of the DRS and the ITS used in this investigation are shown in Fig. 2. The basic properties of the collected DRS are shown in Table 1, where soil consistency limits were measured by Casagrande method according to ASTM D 4318 [19], and particle size distribution were tested by the combined dry sieving and hydrometer (ASTM D 6913/D 422) [20,21]. The initial water content, Liquid limit (*LL*), Plastic limit (*PL*) and Plasticity index (*PI*) of DRS are 85%, 61.5%, 32.3% and 29.2%, respectively. The particle size distribution of the collected DRS, ITS and D60I40 (the typical mixture of DRS and ITS with a wet mass ratio of 60 to 40) are also shown in Fig. 3. The average particle diameter of the DRS, ITS and D60I40 are respectively 4.5 μm, 250 μm and 24.0 μm. The sand fraction for the DRS, ITS and D60I40 are about 9.1%, 93.4% and 38.2% respectively. Specific gravity was tested according to ASTM D 854 [22], and the specific gravity of the DRS and ITS is 2.65 and 3.57 respectively. According to the plasticity chart of United Soil Classification System (ASTM D 2487) [23], DRS, ITS, and D60I40 can be classified as sandy elastic silt (MH), poorly graded sand with silt, and sandy silt (ML), respectively.

Table 2 shows the chemical compositions of DRS and ITS by X-ray Fluorescence (XRF), which indicates that DRS mainly contains $SiO_2$ and $Al_2O_3$ with contents of 56.65% and 15.31%, while the ITS mainly consists of $SiO_2$ and $Fe_2O_3$ with contents of 63.98% and 12.17%. The mineral compositions of DRS and ITS were also determined by X-ray diffraction (XRD) in Fig. 4. The results show that DRS includes quartz, feldspar, calcite and clay minerals, while ITS is mainly composed of quartz, calcium carbonate, mica and illite.

To modify the behavior of the mixture of DRS and ITS to fulfill the requirement as a suitable backfilling material, OPC and CCS (see Fig. 2) were selected as two optional binders. The chemical compositions of OPC and CCS are shown in Table 2. OPC cement consists mainly of CaO and $SiO_2$ with contents of 62.79% and 21.32%. CaO constitutes the major component of CCS, suggesting that CCS is similar to the hydrated lime shown in Fig. 4.

### 2.2. Sample preparation

A predetermined water quantity was first added to the finely grounded DRS powder passing through No. 10 sieve (2 mm in maximal diameter), and then the slurry was mixed to obtain homogeneous initial moisture content (85.0%) to simulate the in-situ state. ITS was then applied and mixed with the slurry to form the mixture of DRS and ITS. OPC and CCS were then poured into the mixture of DRS and ITS, and stirred by a mixer for about 3 min to achieve a homogeneous paste (CSM is abbreviated as the composite stabilized material/paste). The slump flow test was carried out immediately after this mixing. The proportions of the mixtures involved in this investigation are presented in Table 3.

After evaluating the flowability, the fresh paste was poured into cylindrical moulds with an inner diameter of 50 mm and a height of 50 mm to prepare specimens for the unconfined shearing strength (UCS) test. The moulds were shaken by vibrator during the pouring to remove trapped air bubbles. The demolded samples were wrapped in sealed plastic bags after first 24-hour curing and then cured again in a standard curing room with 20 ± 2 °C in temperature and 95% in relative humidity (RH).

### 2.3. Testing methods

The flowability that is a fundamental property of CSM paste can be measured by the slump flow test (ASTM D6103-97) [24]. A smooth cylinder with 76 mm in inner diameter and 150 mm in height was placed on a glass base. The slump cylinder filled with the CSM paste, was rapidly lifted. After the paste stopping to flow, the mean slump flow diameter in two perpendicular directions was measured.

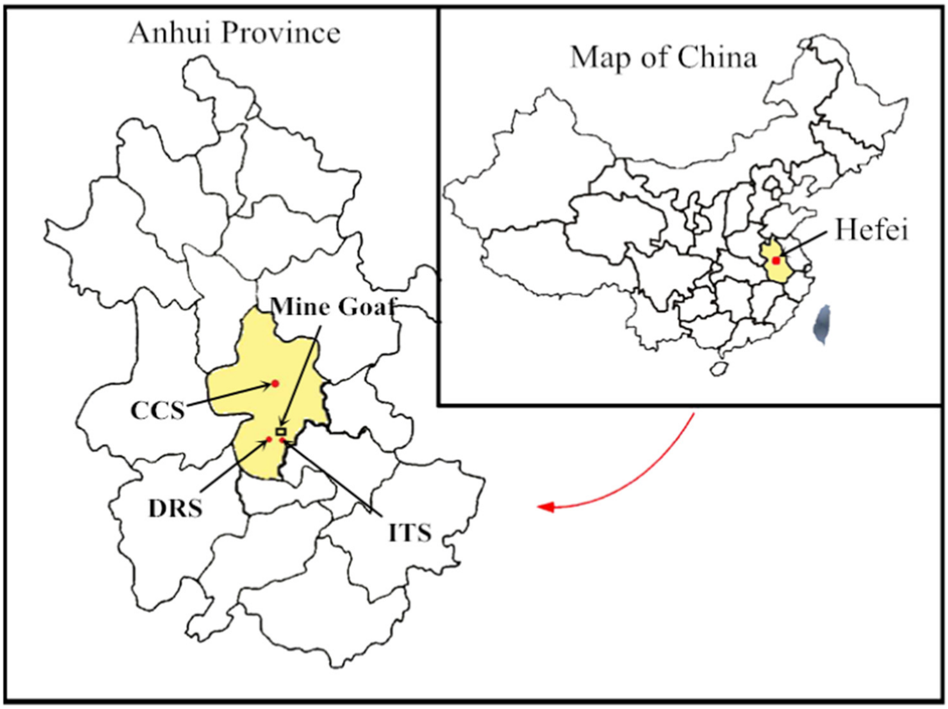

**Fig. 1.** Location of DRS, ITS, CCS and goaf mine.