Utilization of two stage concreting method in the case of steel slag aggregate concrete

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Abstract. Firstly, developed in the years of 1930, two stage concrete is considered as a unique concreting method that is different from conventional concreting method. The first stage consists of pre-placing coarse aggregates in the formwork and the second stage consists of filling voids between aggregate particle with grout mortar of cement. In this paper, we studied the feasibility of casting two stage concrete with 100 % steel slag as coarse aggregate. In term of formulation, to adopt two stage concreting method we could minimize the risk of concrete bleeding and segregation due to high water absorption and quite high density of slag aggregate. In term of resistance, the evidence of solid cohesion between mortar phase and slag aggregate was revealed on 28 days – cured concrete specimens. And the compressive strength was measured at 28.3 MPa. From that, we discussed on the possibility of slag aggregate concrete for the purpose of large scale recycling steel slag with sustainability.

1. Introduction
As we known, steel slag is a solid waste or by-product from the processing of iron (pig iron and/or steel-scrap) to steel in a conversion furnace. This conversion process aims to remove impurities such as Al, Si, P… in order to obtain steel with higher resistance [1]. In Vietnam, they estimate an amount of 1-1.5 million tons of steel slag which is released each year by steelmaker industries. Huge amount of slag occupies ground for dumping and leads to serious environmental issue due to their high content of heavy metal and fine dust [2]. Thus, to recycle steel slag must be considered in the circumstance of economic demand and environment impact. One solution that could be fitted to the purpose of large scale recycling steel slag is to use as aggregate for asphaltic and/or cement concrete. For the feasibility, in one hand, steel slag aggregate must be characterized and processed in order to meet the requirements of standard for concrete aggregate, and in the other hand, material engineers should adapt the concrete technology with regard to specification of steel slag [3].

In concrete technology, Two-Stage Concrete (TSC) or also named Pre-placed Aggregate Concrete (PAC) applies a special concreting method which differs from that of conventional concrete [4]. They skip the step of mixing together coarse aggregates and cement mortar in the concrete mixer. Instead of that, coarse aggregates are pre-placed in the formwork and mixed grout mortar is then injected into the formwork in order to fill voids between the pre-placed aggregates. Such unique placement technique offers several technological advantages in modern concrete technology. In term of cost benefit for concrete production, we highlight that only 40% of material goes through mixing and pumping procedures [5]. In term of application, two stage concreting method shows advantage for underwater construction, for structural member with closely spaced reinforcement, for repair and/or strengthening
the deteriorated structures [6]. However, they still be limited in the usual building and construction site in comparison with normal ready-mixed concrete. Considering its sustainability, we need discover new possibilities and applications for TSC through adjusting and improving its properties [4].

In the following paragraphs, we will conduct experimental studies on the possibility of using steel slag aggregate and TSC method for concrete production. The first step consisted of processing and characterizing raw steel slag in order to be used as coarse aggregate for concrete. The next step is dedicated to investigate on the formulation of grout mortar, on casting and testing concrete specimens in laboratory condition. In literature, many author preferred to use steel slag aggregate for asphalt concrete instead of cement concrete. They claimed that high water absorption of steel slag particle could affect on the workability of ready-mixed concrete [2]. The fact that we adopt two stage concreting method due to its capacity to ensure the stability of fresh concrete without segregation. Furthermore, we almost highlight that there is no limitation of particle size of coarse aggregate in two stage concrete. Thus that could be an advantage for large scale steel slag recycling in Vietnam without costly slag processing. In the conclusion, we will discuss on the feasibility of this laboratory investigation that could permit us to extend this study in concrete production.

2. Materials and experiments

2.1. Material preparation and experiments

Rough gravel of slag with particle size >800 mm was collected from landfill of Vietnam steel plant in Ba Ria – Vung Tau province. They then were crushed by laboratory jaw crusher, iron removal by permanent and kept storage outside within 3 months. Actually, such external storage combined with daily water spray aim for enhancing the volumetric stability of slag gravel. After such treatment, slag gravels were sized by using the set of sieves 4.75, 12.5, 25 and 37.5 mm. In practice, the use of fine slag and coarse slag for ground leveling and/or for soft soil stabilization is recommended. In this study, we try to valorize coarse slag gravel that was retained on the sieve 25 mm in two stage concrete. We first measured density, water absorption, mechanical resistance of slag with regard to the criteria values of national standard for concrete coarse aggregate. The results are pointed out in the right hand in figure 1. Compared to calcite based aggregate, slag gravel showed higher density (3.33 vs. 2.65) probably due to the remaining steel scrap component. Result of water absorption was 1.7±0.5 %wt that is slightly higher than 0.5 %wt of calcite aggregate. We can explain this phenomenon of important water absorption by considering the intrinsic porous microstructure of slag particle. In addition, such porous microstructure of slag causes negative impact on the strength of slag aggregate.

| Specific properties | Results     |
|---------------------|-------------|
| Density             | 3.33        |
| Water absorption (%wt.) | 1.7 ± 0.5  |
| Crushing strength (MPa) | 60÷80      |

Figure 1. Steel slag aggregate ≥25 mm and results of specific test

To formulate grout mortar, we started with four materials: Portland cement PC40, fine river sand, tap water and superplasticizer admixture. It is noted that the key controlling factor of the performance of two stage concrete is the quality of the grout mortar. Grout mortar with high fluidity could be conducive to effectively filling the space between preplaced aggregates and reducing the voids volume in hardened concrete to a minimum [5]. Portland cement PC40 of Vicem – Ha Tien 1 is a commercial product. And the product specifications are conforming to the requirement of national standard TCVN 2682:2009 for Portland cement. Before using in mixture, river sand was carefully washed with water, dried in temperature chamber and then went through sieve analysis. We obtained the calculated value of finesse modulus 1.6 with large amount of fine grain passing sieve 0.63 mm. BASF MasterGlenium
ACE 8588 was used as superplasticizer admixture. We tested the chemically compatibility with cement PC40 - Vicem - Ha Tien 1 and estimated upper dose limit of 1.2 % by weight of cement.

The following figure schematizes our experimental work with two consecutives steps: (i) material characterization of steel slag as concrete coarse aggregate; (ii) casting and testing two stage concrete in laboratory where we used steel slag aggregate.

During the second step of concrete casting, coarse aggregates of steel slag were preplaced in the steel mold \( \phi 150 \times 300 \) mm. A PVC pipe \( \phi 21 \) mm was placed vertically in the center of the cylindrical mold (figure 3). Then, formulated grout mortar was introduced via PVC pipe in order to fill the spaces between the preplaced aggregates. Meanwhile, the PVC pipe was carefully pulled out and we used a plastic hammer to tap continuously around the mold height for removing the entrapped air bubbles in mortar. It is noted that there is no need consolidating step by vibrator in two stage concreting method as required in case of conventional concrete. Excessive grout mortar was then leveled and removed from cylindrical mold. After 24 hours, concrete specimens were demolded and placed curing in water tank 28 days for strength development. For hardened concrete, we tested mechanical strength, cross-sectional image and compression failure of concrete cylinder.

2.2. Mix design for grout mortar and mixing procedure

For the quality of grout mortar, the following three criteria: flowability, stability and compressive strength must be controlled. Among those, the flowability of fresh mortar means the ability to flow uniformly during a period of time, according to the ACI 304.1. As described in the standard ASTM C938, we could adopt flow cone method to measure flowability of grout for preplaced-aggregate concrete. They consist of measuring the time of efflux of a volume of 1725 ml of grout through the cone discharge tube \( \phi 12.7 \) mm. The phenomenon of uneven flow and/or inconsistency of grout are also remarked during such flow cone test. Those two parameters help us to optimize the composition of mixture [6]. Additionally, mixing procedure might also affect on the rheological behaviour of grout mortar. Deep mixing method is generally adopted for preparing grout mortar of TSC [6]. Dry mixture of cement, fine aggregate was firstly realized in the normal planetary mortar mixer (Matest E095). After that, we used a hand-held mixer EHR 15.1 SB to mix the above mixture of cement and fine aggregate with water and superplasticizer in a 25 litters plastic bucket. Special paddle \( \phi 40 \) mm allows us mixing from the bottom up, eliminating injection of air for a uniform blend. High-torque motors provide us maximum power for a rotation speed in the range of 0 - 450 rpm. During 4 minutes of mixing period, fine cement grain could be easily dispersed in the mixture to make improvement to the global viscosity of fresh mortar.
Different trial mixes of grout mortar were tested in the laboratory condition. In general, proportional mixture of grout mortar was selected with regards to the recommendation of ASTM C938-210. Various parameters should be considered in the mix design, including: water-cement ratio (W/C), sand-cement ratio (S/C) and the content of superplasticizer.

| No. | Proportional mixture of 1725ml grout W/C | S/C | Superplasticizer (% wt of cement) | Time of efflux (s) | Specific remarks of flow |
|-----|---------------------------------------|-----|---------------------------------|-------------------|-------------------------|
| 1   | 0.35                                  | 1.0 | 0.40                            | 34                | Very high viscosity, not flowing |
| 2   | 0.35                                  | 1.0 | 0.45                            | 32                | Flow but quite high viscosity |
| 3   | 0.35                                  | 1.0 | 0.50                            | 28                | Sufficient flow |
| 4   | 0.35                                  | 1.0 | 0.60                            | 26                | Sufficient flow |
| 5   | **0.39**                              | **1.0** | **0.40**                            | **20**           | **Very good flow** |
| 6   | 0.40                                  | 1.0 | 0.40                            | 18                | Flow with quite high fluidity, water bleeding |
| 7   | 0.40                                  | 1.5 | 0.50                            | 77                | High viscosity, not easily flowing |
| 8   | 0.40                                  | 1.5 | 1.0                             | 44                | High viscosity, not easily flowing |
| 9   | 0.45                                  | 1.5 | 0.5                             | 27                | Flow with minor segregation |
| 10  | 0.45                                  | 1.5 | 1.0                             | 22                | Flow with major segregation and water bleeding |
| 11  | 0.50                                  | 1.5 | 0.4                             | 16                | Flow with high fluidity, water bleeding |

As given in the table 1, by varying the water-cement ratio, sand-cement ratio and dosage of superplasticizer, we obtained completely different rheological behaviour of formulated mortar. In one hand, both high water-cement ratio and an appropriate content of superplasticizer are conducive to the good flowability for grout mortar. And in the others hand, high sand-cement ratio affect on the efflux time, grout stability due to the higher friction between sand particle. Preliminary results revealed that good flowability was obtained in the case of trial mix number 5 (W/C=0.39, S/C=1, admixture 0.4 %wt of cement).

3. Results and discussion

3.1. Properties of grout mortar
Based on the designed mixture (W/C=0.39, S/C=1.0, admixture 0.40 %wt of cement), we characterized in the next step the property of mortar at both early and later age. The obtained results were summarized in the following table.

### Table 2. Result of characterization of prepared grout mortar

| Proportional mixture of 1725ml grout | Measurement of efflux time (s) |
|-------------------------------------|-------------------------------|
| W/C 0.39  | S/C 1.0  | Superplasticizer (%wt of cement) 0.40 | 0 min | 30 min | 60 min | 90 min |
|          |         |                                            | 20    | 24     | 26     | 29     |

- **Test of water bleeding**
  - Initial grout (ml) 800±10
  - Water bleeding after 3 hours (ml) 1.5±0.1
  - Bleeding (%) 0.19

- **Test of setting time**
  - Initial setting time (min) 475
  - Final setting time (min) 535

- **Test of compressive strength**
  - 3 days 60.2±1.3
  - 7 days 65.2±1.9
  - 28 days 79.9±0.5

3.1.1. **Loss of grout flowability**

As reported in the table 2, after the mixing stage we measured the efflux time of grout at 0, 30, 60 and 90 minutes. It is noted that before each cone flow test grout mortar was stirred to maintain consistency. It was logical to find that the recorded values of efflux time evolve in function with time. Mainly due to the hydration reaction of cement, they constantly increase the global viscosity of grout mortar. That also means a loss of grout flowability. Between 0 and 90 minutes, the difference of efflux time reached 45 %. And only after 30 minutes, it seems that flowability did not meet the requirement of standard ASTM C938 for grout of TSC. We do pay attention this factor during the next step of concrete sampling.

3.1.2. **Bleeding**

As we known, bleeding occurs due to the settlement of heavier solid particles suspended in water under their own weight [7]. We realized test of water bleeding of 800 ml of grout mortar with regards to the instruction of standard ASTM C940. As given in the table 2, bleeding result was recorded as 0.19 % after 3 hours that could meet the required limitation <0.5 % of ASTM C938 for grout mortar of TSC. Quite low value of bleeding measurement means low excess water in the designed mixture of grout mortar. Such evidence might also contribute to increase the mechanical strength and to reduce drying shrinkage of hardened mortar.

3.1.3. **Setting time**

To ensure that grout can be injected through preplaced aggregate, we must control the initial and final setting time of fresh mortar. As instructed in the standard ASTM C953, we conducted test of setting time by using the Vicat apparatus. Result of late setting period as given in the table 2 permit to extend the application of grout before its hardening.

3.1.4. **Compressive strength**

We realized test of compressive strength on prismatic specimens (40x40x160 mm) of hardened mortar after 3-7-28 days of curing period. It should be noted that due to its flow, prism mortar was moulded without the use of a jolting table for compacting. In order to remove possible entrapped air, we only stirred grout in mould several times during the casting step. As given in the table 1, early age compressive strength (after 3 days of curing time) was very high and there existed only a small difference between those of 3 and 7 days. That means rapid strength development was recorded in case of formulated grout. This can be explained by the fact that we have used superplasticizer in the
mixture and high content of cement. The final strength at 28 days is near 80 MPa. This result promises to produce concrete with strong bonding of mortar. But certainly the final strength of concrete depend on both strength of mortar and aggregate components.

3.2. Results of two stage concrete with steel slag aggregate
The formulated grout mortar in the previous step was used for concrete sampling in cylinder mould φ150x300 mm with preplaced steel slag aggregate.

3.2.1. Cross-sectional image of concrete cylinder

![Cross-sectional image of concrete cylinder](image)

Figure 6. Photo taken from cutting surface of concrete cylinder (left) original image; (right) zooming areas of A & B

Figure 6 shows the photo taken from the cross section of hardened concrete cylinder. We observed that grout mortar was filling the pores between slag particles. This created a compact microstructure of concrete specimen. But it seems that due to rough shape and large size of raw slag the density of aggregate area is rather low. By using an image analysis software, we estimated 35% of its area value in this photo taken. In general, this can lead to the excessive use of mortar for concrete casting. Zooming image on the right hand allow us to identify the transition area between slag aggregate and cement mortar. There is a good coherence between those two phases. Number of holes in the mortar phase due to trapped air during the stage of grout mixing. The microstructure of slag aggregate quite porous. They might consequently affect on the mechanical resistance of concrete.

3.2.2. Compression failure
Figure 7 shows the photo of a broken concrete after compression testing. From that we can conclude a rapid failure mode of the cylinder concrete under compressive loading. The development of meso-cracks and macro-cracks and their connection lead to the final destruction of concrete sample. We also noted that around the contour of the concrete cylinder they exist some locally closed cracks. In the right hand image, we can observe different falling parts that we draw from those local cracks. It seems that vertical fissure easily pass through a number of slag particles. This can be considered as weak link in the microstructure of two phases (mortar and slag aggregate). As illustrated in the previous cross-section image, we also observed a good coherence between those two phases in the cliché of falling parts. Some pore positions also could be recognized inside the broken slag gravel.
3.2.3. Strength development

The results of compressive strength of prepared concrete cylinder were summarized in figure 8. It is noted that in general different packing status of preplaced aggregate particle might affect the final resistance of TSC. But considering the results that we obtained in figure 6, they only contained a small deviation among five concrete cylinders tested at each age days. From 3 to 28 days, compressive strength evolve mainly due to cured cement mortar. At 28 days, 28.3 MPa compressive strength of concrete cylinder is slightly small while comparing to the 79.9 MPa compressive strength of hardened mortar. This can be easily explained by weak link of slag aggregate in the concrete microstructure. At this point, we should consider a strategy to enhance the mechanical properties of slag aggregate and increase the density of aggregate area. However, with regards to the specification of national standard TCVN 3118:1993 for normal concrete material, such results of strength can be classified the prepared TSC into the M300 grade.

4. Conclusions

For concluding, we conducted studies on the use of two stage concreting method in producing concrete with 100 % steel slag EAF as coarse aggregate. At the laboratory scale, experimental results of specification of slag aggregate, formulation of grout mortar and concrete characterization was analyzed.

- For the steel slag aggregate, measurements of density, water absorption and crushing strength are respectively 3.33, 1.7±0.5 and 60÷80 MPa. That means in comparison with calcite
aggregate lower density, higher water absorption and lower strength we obtained in the case of slag aggregate.

- For the formulation of grout mortar, designed mixture of W/C=0.39, S/C=1.0, admixture 0.40 \%wt of cement shows the evidence of high performance grout for two stage concrete both in term of flowability and in term of strength.
- For the characterization of two stage concrete, we highlighted the good cohesion at the interface of mortar and steel slag gravel and also 28.3 MPa compressive strength of 28 days concrete specimens. Two stage concrete with 100 \% steel slag aggregate could be classified into grade M300 according to national standard TCVN 3118:1993 for normal concrete.

For future studies, we will focus on enhancing the mechanical resistance of steel slag aggregate and on investigating the durable behavior of two stage concrete compared to those of normal concrete structure.

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