Investigation of slag supplementary to the concrete rigid pavement mix design

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Abstract. The utilization of slag as cement replacement has been widely developed for the concrete mixture. It is shown by the increment of the concrete performance even though unique characteristics during the cement-slag reaction were present. Slag is the waste of the steel industry which has various qualities. Unfortunately, this type of waste is not well identified in past research as supplementary material for the concrete. This paper will study the best proportion of slag cement as supplementary material in concrete for the special use of the rigid pavement. Solely, the mix design criteria for the experiment is not available yet so that preliminary experiment both physical and chemical are investigated for the special purpose of the target of minimum high strength concrete of 35 MPa. The chemical substances of two main oxides of sodium and potassium from ordinary Portland cement is essential to see the alkali activity that leads to the strength quality of the concrete specimen. Otherwise, the consideration of water-cement ratio must be relevant to the quality of concrete matrices.

1. Introduction

Generally, pavement is divided into flexible and rigid pavement which differ in the presence of bituminous material. Rigid pavement mostly made of high strength concrete to convince good performance in absorbing dynamic load from the vehicles. High strength concrete usually has special performance such as high strength and durability, low permeability and high workability. However, the drawbacks are included such as high self-desiccation and heat of hydration of concrete that will lead to early age of concrete crack [1]. In order to solve the crack, the utilization of ground granulated blast furnace slag (GGBFS) as mineral admixture is introduced lately. It is proven in reducing the heat produced by cement hydration and improving the comprehensive performance of concrete [2].

Considering GGBFS as replacement or addition of cement has been widely researched and shown good results to the concrete performance. GGBFS was produced from molten blast furnace slag which was rapidly chilled by immersion in water. It is non-metallic product, consisting essentially of silicates and aluminosilicates of calcium and other bases [3]. The contribution of GGBFS to the hydration after 28 days will consequently improving the mechanical property and durability at long-term as the result of pozzolanic reaction from it [4].

Mix design of concrete incorporating GGBFS as cement replacement for the highway pavement has been developed in the past years as it is successful to reach the grade 120 slag. However, some factors such Portland cement used, aggregate type and slag replacement proportion were considered essential.
Simply, addition of GGBFS has its own easiness to match any project conditions and meets the fineness as good as cement. Meanwhile, the addition of GGBFS to the concrete mixture has not fully concerned so that further mix design modification could be important to find its effectiveness in obtaining best concrete performance.

2. Mix design
According to Nasional BS, the procedure of mix design must comply some or all the requirements such as: (a) water-cement ratio; (b) minimum cement content; (c) air entrainment; (d) slump; (e) maximum aggregate size; (f) target strength; and (g) other requirements related to admixtures, cement type, aggregate and other cementitious material. Moreover, they should be able to produce sufficient workability, durability, strength and economical [6].

2.1. Mix design parameters
In table 1, we can notice that the absorption and fineness modulus of fine aggregate were not satisfied the aggregate for concrete design. Thus, the lower strength of concrete performance can be anticipated. Concerning the specific gravity of the GGBFS was quite low, the density of concrete was expected for gaining slight change from the mix design as the maximum addition of the GGBFS was 20% from the weight of cement.

### Table 1. Preliminary test of concrete components.

| Material          | Specific gravity (SG) (gr/cm$^3$) | Water content (%) | SSD SG (gr/cm$^3$) | Apparent SG (gr/cm$^3$) | Absorption (%) | Fineness modulus (%) |
|-------------------|-----------------------------------|-------------------|-------------------|---------------------|----------------|----------------------|
| Portland cement   | 3.15                              | -                 | 2.57              | 2.63                | 0.83           | 7.53                 |
| GGBFS             | 0.963                             | 4                 | 2.55              | 2.57                | 1.02           | 7.53                 |
| Coarse aggregate  | -                                 | 0.77              | 2.55              | 2.57                | 1.02           | 7.53                 |
| Fine aggregate    | -                                 | 0.37              | 2.57              | 2.3                 | 11.36          | 3.5                  |

Besides, the chemical properties of ordinary Portland cement (OPC) and GGBFS conducted using SEM (Scanning Electron Microscopy) test as shown in table 2. Various result of the chemical properties of OPC and GGBFS would result different slag activity. As Materials AS required alkali content from sodium oxide and potassium oxide ($\text{Na}_2\text{O} + 0.658 \text{K}_2\text{O}$) ranging from 0.6% to 0.9% in order to observe the significant influence of GGBFS in the concrete mixture. Nonetheless, the absence of both oxides may be difficult to see their contribution to the performance of concrete.

### Table 2. Chemical compositions of OPC and GGBFS (%).

| Chemical substances | Recent experiment | [1] | [4] |
|---------------------|-------------------|-----|-----|
|                     | OPC               | GGBFS | OPC   | GGBFS | OPC               | GGBFS |
| SiO$_2$             | 19.39             | 34.80 | 19.90 | 34.62 | 20.58             | 42.20 |
| Al$_2$O$_3$         | 5.46              | 14.79 | 4.60  | 11.82 | 4.90              | 5.85  |
| Fe$_2$O$_3$         | 4.90              | 1.34  | 3.00  | 2.73  | 4.70              | 1.90  |
| CaO                 | 62.82             | 45.20 | 64.60 | 37.73 | 62.80             | 42.20 |
| MgO                 | 1.50              | 0.99  | 0.78  | 9.43  | 0.53              | 4.72  |
| SO$_3$              | 2.30              | 1.74  | 2.37  | 1.42  | 2.28              | 1.54  |
| Na$_2$O             | ND                | ND    | 0.06  | 0.35  | 0.14              | 0.12  |
| K$_2$O              | ND                | ND    | 0.65  | 0.5   | 0.42              | 0.43  |

Note: ND = Not Detected
The slag activity for three grades of slag cement concrete (80, 100 and 120) is divergent for the 7- and 28-day index concrete samples. The slag activity index of 75% must be reached by grade 100 slag (7-day) and grade 80 (28-day). Interestingly, grade 120 slag may acquire 115% slag activity index after 28 days.

2.1.1. Mix design references.
Initially, the mix design for the compressive strength target of 35 MPa employing the GGBFS as the addition of concrete was calculated using SNI 03-7656-2012 resulted water-cement ratio of 0.47. The detail proportion of each component was served in table 3. Next, another reference from Board M-W C I gave the water-cement ratio of 0.423 for the same strength target design. Another one, based on the discussion with the concrete laboratory of Torsina Redicon in order to reach the target design, the water-cement ratio of 0.4 was determined.

### Table 3. Proportion per 1 m³ of concrete.

| Material        | SNI 03-7656-2012 (kg) | Mid-West (kg) | Torsina Redicon (kg) |
|-----------------|-----------------------|---------------|----------------------|
| OPC             | 410.64                | 294.83        | 410.64               |
| Water           | 193                   | 124.74        | 164.26               |
| Fine Aggregate  | 585.48                | 769.55        | 585.48               |
| Coarse Aggregate| 1190.88               | 1190.88       | 1190.88              |
| Total weight    | 2380                  | 2380          | 2351.26              |

The design from Mid-West Concrete Industry Board had provided the proportion of minimum cement content which was 600 pounds for the design slump of 2 inches. The proportion of the fine aggregate and coarse aggregate was obtained as easy as SNI procedure. However, the proportion of the cement resulted here below 310 kg as usually proposed by experiment in order to reach high strength concrete. Thus, the final design using water-cement ratio by modifying SNI was selected as the midpoint of the mix design. However, there is slightly different result in the total weight per meter cube of concrete mix.

3. Discussion
Mix design provision is practically following the same approaches from one country to another since it has been established around the world. Basically, the methods of concrete mix design are based on empirical relations, charts, graphs and tables developed through extensive experiments and investigations using local material available in certain country [8].

The addition of 20% GGBFS to the concrete mixture was still below 50% as the required admixture of slag type should be less than 50%. The detail proportion differed in the water proportion so that the total weight of the proportion results differently as seen in table 4. The low specific gravity of GGBFS = 0.963 gr/cm³ must be well noticed to the final result of the concrete performance after testing. Moreover, the notable oxides contributing to the alkali activity in this paper are not present.

### Table 4. Concrete mix design proportion including GGBFS per 1 m³ (in kg).

| Mix provision | design | GGBFS Percentage | OPC  | GGBFS | Water | Fine Agr. | Coarse Agr. | Total weight |
|---------------|--------|------------------|------|-------|-------|-----------|-------------|--------------|
| **SNI 03-7656-2012** |        |                  | 5%   | 410.64| 20.53 | 193       | 564.95      | 1190.88      | 2380         |
|                |        |                  | 10%  | 410.64| 41.06 | 193       | 544.42      | 1190.88      | 2380         |
|                |        |                  | 15%  | 410.64| 61.60 | 193       | 523.89      | 1190.88      | 2380         |
|                |        |                  | 20%  | 410.64| 82.13 | 193       | 503.35      | 1190.88      | 2380         |
|                |        |                  | 5%   | 410.64| 20.53 | 164.26    | 564.95      | 1190.88      | 2351.26      |
|                |        |                  | 10%  | 410.64| 41.06 | 164.26    | 544.42      | 1190.88      | 2351.26      |
|                |        |                  | 15%  | 410.64| 61.60 | 164.26    | 523.89      | 1190.88      | 2351.26      |
|                |        |                  | 20%  | 410.64| 82.13 | 164.26    | 503.35      | 1190.88      | 2351.26      |

4
Water-cement ratio got from SNI was quite high since the initial property of absorption and fineness modulus did not meet the requirement for the concrete matrix. Thus, the proportion of water and cement might create watery mixture and the strength of the concrete would rely on the other matrices such as sand and cement. However, as the water is reduced, cement binding and concrete matrices will result better quality.

4. Conclusion

In conclusion, some recommendations for conducting the experiment of GGBFS as the additive in concrete will be as follow:

- The option of using better quality of fine aggregate are strongly recommended.
- As for reaching the target strength of concrete, better for collecting some other references of trial mix design incorporating additive.
- Revised mix design could be applied due to inappropriate quality of fine aggregate so that it could save the target strength.
- GGBFS as the essential additive in this experiment, should be detailed check of its chemical substances. However, once the sodium oxide and potassium oxide are not present, another challenging research will be available in the future.
- In order to reach the target strength, water-cement ratio is not the only option to be reset. Increasing the proportion of better coarse aggregate is one other way.
- Further, analysing the result of several days of test range and concluding the results of each trial mix designs will be a good database for getting a valid mix design of GGBFS as the supplementary material in concrete without replacing cement.

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