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RESEARCH ARTICLE

# CHARACTERISTICS AND APPLICABILITY OF GRANULATED BLAST FURNACE SLAG (GBFS) AS CONSTRUCTION MATERIALS IN VIETNAM

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**Abstract**: *Granulated Blast Furnace Slag has been used for concrete admixtures for a long time in Vietnam, but it has not noticed for many other purposes of construction. Many factories of iron and steel productions in Vietnam are not interested in GBFS. The quality of GBFS is often unstable, its composition and properties are often changed. This is one of the barriers to the widespread adoption of GBFS. This paper focuses on the engineering properties of GBFS as a basis for applicability assessment to construction materials. The obtained results indicate that GBFS in Vietnam have grained grade in range of medium to course size, bulk specific gravity is approximate 1.0 g/cm$^3$, specific gravity is less than 2.3 g/cm$^3$ and content of CaO and $SiO_2$ is around 35-38%. It is suitable for civil engineering works and ground improvement materials. However, it should be noted that direct use of GBFS for concrete and mortar will meet difficult and not suitable, so this possibility of application should be further studied.*

**Keywords**: *Granulated blast furnace slag, concrete mixture, slump, flexural strength, compressive strength.*

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## 1. Introduction

Granulated blast furnace slag (GBFS) is material created by rapid cooling of a slag melt of suitable composition, obtained by smelting iron ore in a blast furnace, consisting of at least two thirds by mass of glassy slag and possessing hydraulic properties when suitably activated [1-2]. GBFS mentioned in this study has a coarse-grain sand shape-liked, which is smaller than 5mm and contains less fine-grain composition. GBFS is mainly in form of glass and its grains are extremely angular. The composition of GBFS is a combination of silica and other non-ferrous compositions of iron ore, ash from coke used as a reducing material, and limestone auxiliary material [8]. Fig. 1 shows the process of generating iron and steel slag, and Fig. 2 is a photo of the blast furnace slag of Tuyen Quang iron steel factory.

Nowadays, as a result of improving environmental awareness, iron and steel slag is highly regarded as a recycled material that can reduce impacts on the environment due to its resource-conservation and energy-saving effects. Table 1 gives a general view of primary characteristics and applications of iron slag in the word.

Some resource-poor countries have successfully commercialized GBFS as a substitute for natural sand that Japan is a typical case. However, technological know-how is a trade secret, which could not shared. Therefore, the research to apply GBFS as construction materials is still ongoing in the world.

Scientists have tried to study local GBFS to evaluate the behavior, properties, and the replacement ability for natural sand in fine aggregate of concrete and cement mortar. Among them, Ganesh Babu and Kumar (2000) made an

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endeavor to determine the effectiveness of 28-day curing time of concrete mixture at different levels of GBFS replacement. The GBFS replacement is conducted from 10% to 80% and the compressive strength after 28 days curing were assessed [3]. Kelly (2008) considered GBFS as a material applying to geotechnical engineering and studied under aspect of physical and chemical properties, densification, shear strength, and permeability [4]. A conclusion by Nataraja et al., (2013) from the testing results on GBFS sand confirmed that it can alternate apart of natural sand to GBFS in cement mortar from the view point of compressive strength. The alternative of GBFS may be up to 75 percent [6]. Meanwhile, the amount of that alternative in the study of Sumana et al., (2016) is 50% of fine aggregate [9].

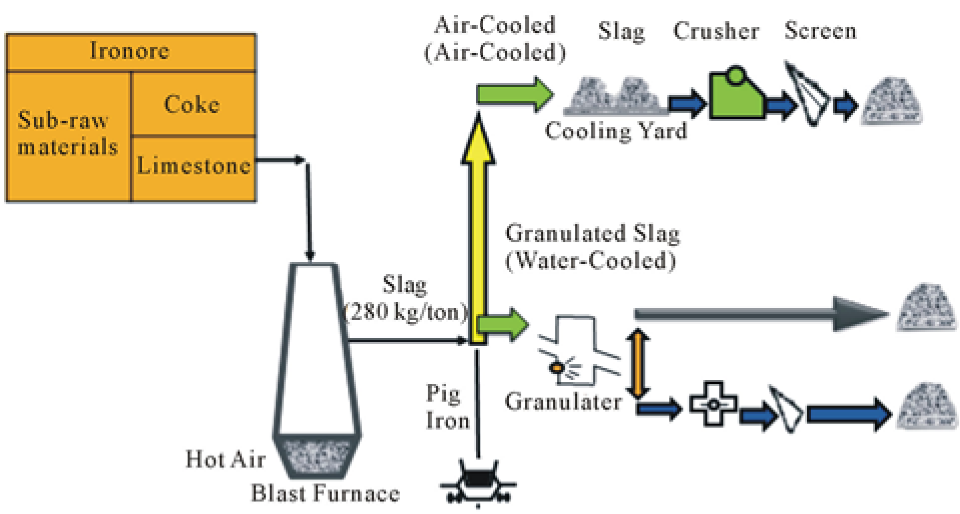


*Fig. 1. Process of generating iron slag*

*Fig. 2. Granulated blast furnace slag of Tuyen Quang iron steel factory*

GBFS has been applied to concrete admixtures in Vietnam for a long time, but applying as material for civil engineering works, ground improvement material, etc., has not almost unnoticed. Many steel and iron factories in Vietnam have not cared about quality of GBFS. In the other words, Vietnam's GBFS has often unstable quality. Its composition and properties are often changed. This is one of the obstacle of application of GBFS to the abundant purpose of construction. Therefore, studying the applicability of GBFS for construction material production in Vietnamese conditions is an urgent requirement in terms of economic, technical and environmental aspects. This study will outline some of the key features of GBFS and their applicability as construction materials.

*Table 1. Characteristics and applications of iron slag [8]*

| Characteristics | Applications |
|---|---|
| Strong latent hydraulic property when finely ground | Raw material for Portland blast furnace slag cement |
| | Blending material for Portland cement |
| | Concrete admixtures |
| Low $Na_2O$ and $K_2O$ | Raw material for cement clinker (replacement for clay) |
| Latent hydraulic property | Material for civil engineering works, ground improvement material (Backfill material, earth cover material, embankment material, road subgrade improvement material, sand compaction material, ground drainage layers, etc.) |
| Lightweight, large angle of internal friction, large water permeability | |
| Does not contain chlorides. | Fine aggregate for concrete |
| No alkali-aggregate reaction | |
| Fertilizer composition (CaO, $SiO_2$) | Calcium silicate fertilizer |
| | Soil improvement |

**2. Methids of study**

To determine and assess the properties of GBFS, this study conducted a series of experiments directly on GBFS and indirectly on GBFS-contained hard concrete. GBFS was compared with NS through indirect experiments. In other words, the slag was considered as fine aggregate in concrete.

***2.1. Sample preparation***

The GBFS used in this study was taken from Tuyen Quang iron steel factory, one of a typical slags in Vietnam. Its chemical composition is given in Table 2. Herein, content of $SiO_2$ and CaO is the most considerable factor. Accordingly, that of $SiO_2$ accounts for 35.86% and CaO is 38.72%.

Materials used in this study include coarse-grain sand shape-liked of GBFS, coarse-medium size of nature sand, Portland cement, and water. Natural sand (NS) used in this research has moderate gradation with specific gravity of 2.64g/cm$^3$, and dry specific gravity of 1.480g/cm$^3$. The analysis results of GBFS and NS are compared to Vietnamese building standard TCVN 7570:2006 [10]. Portland cement used for this study is PC40 with a density of 3.12 g/cm$^3$, a specific gravity of 1.865g/cm$^3$, and surficial area of 340 m$^2$/kg.

*Table 2. Chemical composition of the studied GBFS*

| Chem. comp. | MKN | $SiO_2$ | CaO | $Al_2O_3$ | $Fe_2O_3$ | MgO | $SO_3$ | $Cl^-$ | $S^{2-}$ |
|---|---|---|---|---|---|---|---|---|---|
| **Content** | 0.94 | 35.86 | 38.72 | 11.71 | 0.73 | 8.61 | 0.16 | $<10^{-3}$ | 0.65 |

Beside the preparation of granulated slag samples, the slag was also mixed with NS as partial replacement of fine aggregate in concrete. Four specimen sets were prepared, in which the control mix contains 100% NS and the remaining 3 specimen sets were prepared with different alternative GBFS/NS ratio of 40/60, 50/50, and 60/40, respectively. Crushed rock is an important composition of concrete, which it has diameter of 20mm in maximum. The ratio of water/cement (w/c ratio) was equal to 0.56 and 0.66 in order to keep the initial slump of the mixture around 9.0 and the slump after 30 minutes around 6.0-6.5 among the GBFS/NS ratios. The amount of each material need for concrete is given in Table 3. Those materials were mixed together in order to conduct the experiments and to cast into block with the dimension of 150 x 150x150 mm for compressive strength test and 150x150x300 mm for flexural strength test.

*Table 3. Composition of concrete mixture [7]*

| Sample set | Cement PC40 (*kg*) | Crushed rock (*kg*) | Fine aggregate (*kg*) | | | Water (*l*) |
|---|---|---|---|---|---|---|
| | | | Total | NS | GBFS | |
| $M_0$ | 35.2 | 110.4 | 72.2 | 72.2 | 0 | 19.8 |
| $M_1$ | 35.2 | 110.4 | 72.2 | 43.3 | 28.9 | 21.6 |
| $M_2$ | 35.2 | 110.4 | 72.2 | 36.1 | 36.1 | 22.6 |
| $M_3$ | 35.2 | 110.4 | 72.2 | 28.9 | 43.3 | 23.1 |

***2.2. Bulk specific gravity of concrete mixture***

Fig. 3 shows an image of determination of bulk specific gravity of concrete mixture. The testing procedure is as follows: pour and compact the concrete mixture to a 5-letter volume mold, use a flat ruler to remove the excessing mixture from mold surface, remove the adhesive from the outside and determine the volume of all mold to 0.2% accuracy. This experiment agrees well with construction standard of TCVN 3108:1993.

***2.3. Slump test***

Fig. 4 expresses the images of slump test of the concrete mixture. This is the method of determining the flexibility of the concrete mixture. The experiment are determined by pouring the concrete mixture through a hopper into 3 layers, each layer makes up about one-third the height of the mold. After the concrete mixture is stable, take the hopper out for 5-10 seconds. Measuring the height difference before and after hopper released, and the slump of concrete is then be determined. This experiment is in accordance with construction standard of TCVN 3016:1993 [10].

*Fig. 4. Determination of slump of concrete mixture*

***2.4. Time of setting***

This experiment agrees well with construction standard of TCVN 9338:2012 [11].Before carrying out the experiment, use a pipet tube to remove the water from the surface of the concrete mixture. The penetration resistance is then determined by inserting a needle into a force-meter and the needle surface contact with the mixture surface. Apply force vertically to the force-meter slowly until the needle penetrates deep enough into the mixture (25 ~ 2) mm. The time required for penetration is 10 ~ 2 s. Measuring the penetrated force and the trial time. The penetration resistance is, therefore, calculated by dividing the recorded penetrated force by the area of the tip of the needle. Recording the calculated results with the precision up to 0.1 MPa

*Fig. 3. Determination of bulk specific gravity of concrete mixture*

**2.5. Compressive strength**

The compressive strength is determined by testing with the sample sets. Each set consist of three specimens. The standard size of a piece for determination of compressive strength is 150×150×150 mm. Compressive strength is inspected for each specimen set with curing time of 3, 7, and 28 days. Defining the force-bearing area of the specimen with measuring precision of parallel edge pairs of two compressed sides up to 1mm. The determining of compressed area of the top and bottom sides is in accordance with the average values. Thence, the failure load is defined. The maximum force obtained is the load need to destroy the sample.

Compressive strength is calculated by the following equation: $R = \alpha \times \frac{P}{F}$, where P is the failure load (daN), F is force-bearing area of the sample ($cm^2$), α is the conversion coefficient.

***2.6. Flexural strength***

Fig. 5 shows the sampling and testing of flexural strength of the GBFS concrete. It is determined by gradually apply load onto three concrete blocks under standard condition until the specimen failed. Specimens were cast into the cylindrical metal mold. The cylindrical specimen is, then, inserted into the flexural system and conducted the experiment by increasing the velocity of applying load from 10N/s – 50N/s until the specimen failed. Recording the maximum load need to the specimen failed. The flexural strength of trial specimen Ru (N/mm$^2$) is then calculated by the equation:

$Ru = 1.5 \times (\frac{P_u \times l}{b \times h^2})$ , where Pu is the flexural force (N), l is the distance between two points of applying force (mm), b and h is the width and the height of the trial specimen, respectively (mm).

*Fig. 5. Sampling and testing of flexural strength*

**3. Results**

3.1. Grained size distribution of GBFS

The curves of grain size distribution of some Vietnamese GBFS are given in Fig. 6. In general, the curves of the slag mentioned here are in range of upper and lower limit of the standard TCVN 7570 [12].

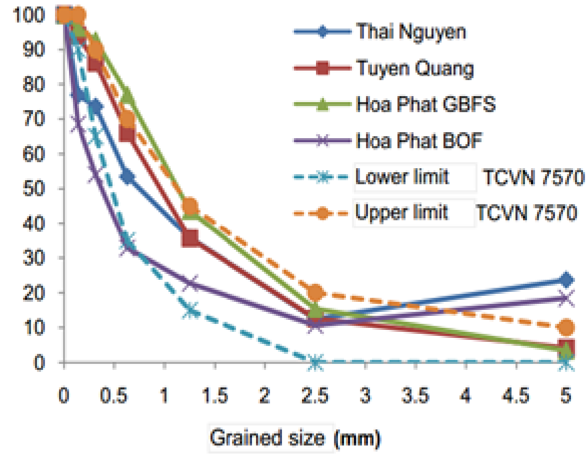


*Fig. 6. Grained size of the GBFS of several sources in Vietnam [5]*

***3.2. Fundamental characteristics of typical GBFSs in Vietnam***

The physical and chemical properties of some GBFSs in Vietnam are given in Table 4 and 5. The chemical composition of general Japanese GBFS in is also given for comparation purpose. It can be seen that some GBFSs in Vietnam have basic properties different from that of Japan, even its composition and characteristics are different from batches.

*Table 4. Typical composition of GBFS in Hoa Phat and Thai Nguyen steel [5]*

| Chemical composition | GBFS Hoa Phat | GBFS Thai Nguyen |
|---|---|---|
| MKN | 0.99 | - |
| SiO2 | 35.54 | 36.12 |
| CaO | 40.95 | 37.65 |
| Al2O3 | 10.95 | 12.74 |
| Fe2O3 | 0.72 | 2.36 |
| MgO | 9.20 | 8.19 |
| SO3 | 0.14 | 0.26 |
| K2O | 0.67 | 0.91 |
| Na2O | 0.43 | 0.16 |
| TiO2 | 0.32 | 0.30 |
| MnO | - | - |
| P2O5 | - | - |
| Cl- | <0.001 | <0.001 |
| S2- | 0.62 | 0.72 |

*Table 5. Typical physical properties of some GBFS in Vietnam (tested results and adapted to [5])*

| Parameter | GBFS Thai Nguyen | GBFS Hoa Phat | GBFS Tuyen Quang |
|---|---|---|---|
| Specific gravity, g/cm$^3$ | 2.297 | 2.558 | 2.473 |
| Water absorption | 2.98 | 2.52 | 2.22 |
| Bulk density, g/cm$^3$ | 0.821 | 1.096 | 1.027 |
| Grain size (by TCVN 7570:2006) | Larger than course grained sand | Course grained sand | Course grained sand |
| Grain > 5 mm, % | 11.8 | 1.7 | 2.1 |
| Modune of grain (grain<5 mm) | 3.12 | 3.36 | 3.07 |

### *3.3. Effect of GBFS on slump of concrete*

The higher slump gets, the more cement, water, and additives are used; so the concrete is dehydrated and separated between rock fragments and cement. The obtained result of changing of slump is shown in Fig. 7. For each sample with different NS and GBFS ratio, the initial slump and the slump after 30 minutes varied significantly. In particular, the significant difference is identified between the specimens of constant water/concrete ratio (w/c = 0.56) and inconstant water/concrete ratios (w/c = 0.56 - 0.66). For the specimen set with w/c = 0.56, the experiments are performed for three sets, i.e., M0 (0% GBFS), M1' (40% GBFS), and M2' (50% GBFS). For the specimen set with the inconstant ratios of w/c = 0.56-0.66, the experiments are performed for four sets, namely, M0 (0/100), M1 (40/60), M2 (50/50), M3 (60/40).As the amount of water keeps constant, the slump of the concrete mixture significantly reduces if the GBFS increases. The initial slump was 9.0cm with 0% GBFS and sharply dropped to 2.5cm and 2.0cm when the GBFS amount reaches to 40% and 50%. The results indicate that the replacement of GBFS will significantly reduce the flowability of the concrete.

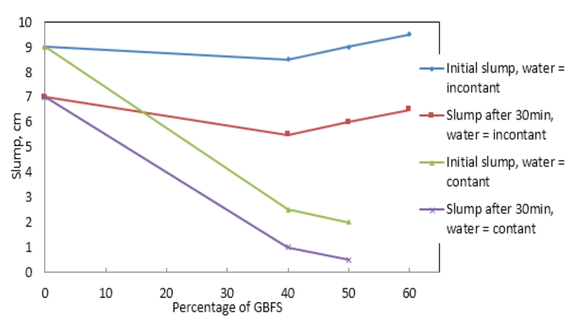


*Fig. 7. Relationship between GBFS and slump of concrete*

### *3.4. Effect of GBFS on setting time of concrete*

The initial setting time and completed setting time for four sets of specimen are taken into account. The obtained results express the relationship between the setting time and the weight ratio of GBFS used in the concrete mixture. Fig. 8 shows that if the weight ratio of GBFS increases from 0 to 60%, the setting time will increases. In another word, the setting time will be longer with the increasing of percentage of GBFS.

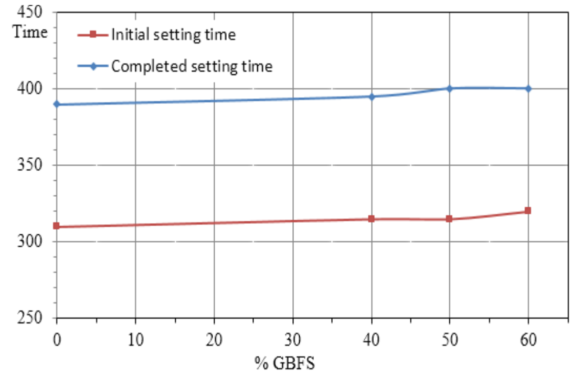


*Fig. 8. Content of GBFS and setting time of the concrete mixture*

### *3.5. Effect of GBFS on compressive strength of concrete*

The compressive strength of the specimens in two cases, i.e. constant and inconstant w/c ratio, was determined to evaluate the strength and the effect of water ratio in the concrete mixture with different percentage of GBFS. Fig. 9 shows the results of compressive strength for different percentage of GBFS in case of ratio of w/c = 0.56-0.66 and initial slump be around 9. From this figure, one can recognize that the compressive strength increases as the curing time get longer. It is observed for all the specimens. In this case, compressive strength at all mixture ratio and all curing time e of replacement GBFS specimens is significantly lower than those of control mix. It also should notice that the percentage of GBFS is lower, the compressive strength is higher.

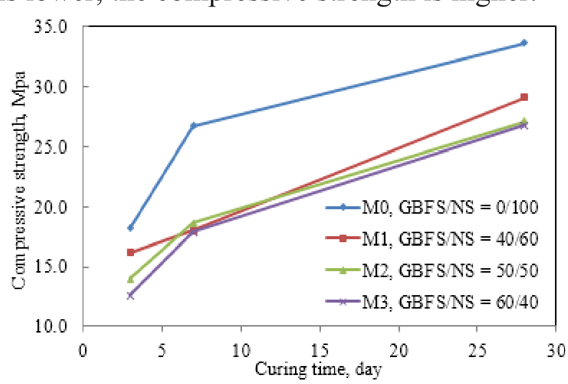


*Fig. 9. Compressive strength of concrete with w/c ratio = 0.56-0.66,slump ≈ 9cm*

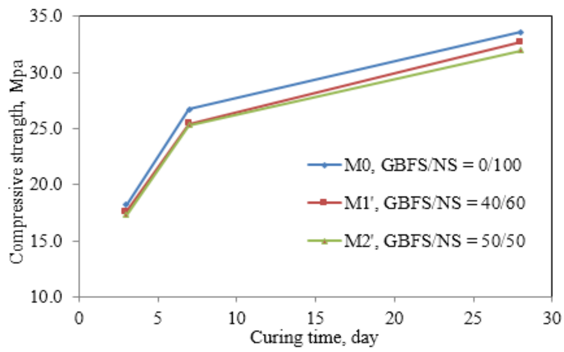


*Fig. 10. Compressive strength of concrete with w/c ratio = 0.56, slump changed*

When the water ratio is constant, i.e., w/c ratio = 0.56, the initial slump decreases from 9.0cm with replacement GBFS = 0% to 2.0cm with replacement GBFS = 50% (Fig. 10). In this case, values of compressive strength of the specimen M1', M2' is approximate that of control mix of M0. The compressive strength values increase gradually over curing times of 3, 7, and 28 days for all specimens with different replacement GBFS. The compression strength is inverse ratio to percentage of GBFS.

### *3.6. Effect of GBFS on flexural strength of concrete*

The flexural strength of concrete is determined to evaluate the bending resistance ability of concrete specimens. This experiment is just performed in case of w/c ratio changed, i.e. slump of all specimens is around 9cm. Fig. 11 expresses the obtained results in case of w/c ratio = 0.56-0.66 and slump ≈ 9cm. It shows that flexural strength of concrete decreases as the percentage of GBFS replaced increases. The difference of flexural strength is remarkable comparing between specimens of replacement GBFS with the control mix specimens. Flexural strength of concrete also increase over time. However, the impressive increase is just obtained from the date of $3^{rd}$ to $7^{th}$. After 7 days the increase gets gradually slow until the date of $28^{th}$.

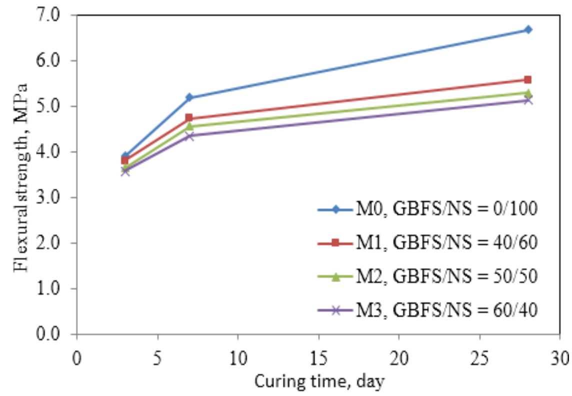


*Fig. 11. Compressive strength of concrete in case w/c ratio = 0.56-0.66, slump ≈ 9cm*

## 4. Discussion

In the recent years, under pressure on natural resources, environmental protection, and economic development, GBFS has been widely used for a variety of purposes. In Vietnam, although a huge amount of GBFS has been produced annually, they are still not cared about utilizing function yet. GBFS herein is just used a part as cement admixture and the remaining is for export purpose. Besides, the quality of domestic GBFS is not controlled, the composition and properties are unstable.

There have been studies about the use of activated GBFS as an additive for cement production, additive for concrete and mortar, backfill material, earth cover material, embankment material, road subgrade improvement material, sand compaction material, ground drainage layers, etc. However, those studies have been in small scale. The authorities association of Vietnam government, i.e. Ministry of Construction, has been issued the guideline on iron and steel slag for use as construction materials after decision No.430/QD-BXD [5], and the related building codes such as TCVN 4315:2007 [13].

A considerable scientific projects aiming at "study granulated blast furnace slag for cement production in Vietnam" have been executed. This study gave the crucial assessments about the use of GBFS as an additive for cement and concrete production as well as their influence on environment and human health. Ministry of Construction of Vietnam has issued the technical guidelines related to use of GBFS. This mentioned about the classification and identification of the properties, the impact on environment of iron and steel slag, and the use as construction materials. The guideline also addresses on the applications of GBFS as the mineral additive for cement, concrete production, as fine aggregates for concrete, material for embankment, road construction, as well as guide for use of iron and steel slag. However, the guidelines is still quite basic, no specific and detail instructions for each types of slag at different stages of designation, construction, and maintenance, etc. Hence, there could be many difficulties during using each type of slag due to the unclear and less detailed instructions. In fact, most of the GBFS in Vietnam has only been used as an additive in cement production. Research and application of GBFS for abundant purposes of construction materials has been almost neglected.

This study contributes to supply several technical properties and characteristics of typical GBFS in Vietnam as a basis for their application for construction materials purposes. The obtained results indicate that GBFS is in range of medium to coarse grained size, bulk density is approximate 1.0 g/cm3, specific gravity is just 2.2 g/cm3, and content of CaO and SiO2 is around 35-38%. This basic properties of Vietnamese GBFS is different from that of Japan as well as other developed countries. Mechanical properties of GBFS is also indirectly evaluated by concrete mixture used a part of this slag. The study experimented two cases of water/cement ratio for the concrete mixture, i.e. w/c ratio is constant and inconstant. As w/c ratio is constant, the difference of compressive strength of the specimens is almost negligible. Although there is also a small gap of compressive strength between control mix of M0 and the replacement GBFS specimens of M1' and M2'. However, the slump of concrete mixture is totally different. The initial slump of M1' and M2' gets 2.5cm and 2.0cm. Concrete mixture with such slump will cause difficulties for the actual construction. For w/c ratio is inconstant, which slump is kept at 9.0cm the difference of compressive and flexural strength between control mix of M0 and the rest ones is significant. Compressive and flexural strength of the specimens decrease as the amount of GBFS increase in the concrete mixture. With the obtained results, one can suggest an optimum ratio of the replacement between GBFS and NS is 50/50. This may be the medium ratio and be suitable for different parameters of concrete. To make the GBFS-concrete approach the quality of NS-concrete, beside GBFS/NS ratio, it is recommended to apply appropriate admixture. This issue should be further analyzed in subsequent studies.

**5. Conclusion**

The quality of GBFS in Vietnam is normally not controlled, its composition and properties are unstable. This may lead to difficulties in applicability of GBFS as construction material purposes. This paper focuses on the technical properties of some GBFSs for construction material purposes. The findings are given below:

- GBFS in Vietnam is commonly in range of medium to coarsed grained size, content of CaO and SiO2 is around 35-38%. This basic properties of Viernamese GBFS is different from that of Japan, where the slag is almost controlled in high and stable quality.

- The mechanical properties of GBFS is indirectly evaluated. In case of the w/c ratio = 0.56, slump of the concrete mixture decreases as the GBFS increases. The compressive strength of the partial GBFS specimens reaches value of the control mix. In case of the w/c ratio = 0.56-0.66, slump is kept almost constant. The compressive strength values at all mixed ratio and all curing time of replacement GBFS specimens is lower than those of control mix. The amount of GBFS is lower, the compressive strength is higher. Flexural strength of the specimens decreases as the amount of GBFS increases. Flexural strength values of the partial GBFS specimens are lower than those of control mix.

- GBFS in Vietnam are suitable for making civil engineering works and ground improvement materials. However, it should take much more studies to make it clearer.

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## References

1. European Standard EN 15167-1, 2006. *Ground granulatedblast furnace slag foruse in concrete, mortarand grout - Part 1: Definitions, specifications andconformity criteria.*

2. European Standard EN 15167-2, 2006. *Ground granulated blast furnace slag for use in concrete, mortarand grout - Part 2: Conformity evaluation.*

3. Ganesh, B.K., Sree, R.K.V., 2000. *Efficiency of GGBS in concrete. Cement and Concrete Research*, 30: 1031-1036.

4. Kelly, B.C., 2008. *Geo-engineering properties of granulated blast furnace slag. Proc. Int. Conference on Geotechnical Engineering "Innovative Geotechnical Engineering"*, Tunis, Tunisia, 24th-26th March, 1: 249-257.

5. Ministry of Construction, 2017. Decision No.430/QD-BXD: *Guideline on iron and steel slag for use as construction materials.*

6. Nataraja, M.C., Kumar, P.G.D., Manu, A.S., Sanjay, M.C., (2013). *Use of granulated blast furnace slag as fine aggregate in cement mortar. International Journal of Structural and Civil Enggineering Research*, 2: 60-68.

7. Truc, N.N., Vu, N.V., 2018. *Partial replacement of natural sand by granulated blast furnace slag (GBFS) in fine aggregate for concrete: practical application in Vietnam*. SGEM 2018, 18 (1.2): 523-530, DOI: 10.5593/sgem2018/1.2/S02.066

8. Nippon Slag Association and Coastal Development Institute of Technology, 2000. *Guidebookfor the Use of Iron and Steel Slag in Port and Harbor Construction*.

9. Sumana, K.K., Sreeja, P.P., Aswathy, M., Indu, M., John, J., 2016. *Replacement of Fine Aggregate by Granulated Blast Furnace Slag (GBFS) in Cement Mortar*. International Journal of Engineering Research & Technology, 05 (03): 801-804.

10. TCVN 3016, 1993. *Heavyweight concrete compounds - Slump test.*

11. TCVN 9338, 2012. *Heavyweight concrete mixtures - Determination of time of setting.*

12. TCVN 7570, 2006. *Aggregates for concrete and mortar - Specifications.*

13. TCVN 4315, 2007. *Granulated blast furnace slag for cement production.*