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# Behavior of Concrete Strength Using Cement Blended With GGBFS and Fly Ash

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*Abstract*— ***The concrete is produced using sand as fine aggregate, crushed stone as coarse aggregate, and mixed with cement and water as the binder. In this study, the focus is on cement mixed with waste material, namely GGBFS and fly ash. Fly ash is a waste product from combustion used in PLTU (Coal-fired Power Plant). GGBFS (Ground Granulated Blast Furnace Slag) is a residue formed during the heating and cooling processes in a blast furnace during steel fabrication. Fly ash and GGBFS contain SiO2; therefore, they can be used as cement substitutes.***
***Based on this, the research was conducted by combining cement, GGBFS, and fly ash to determine the strength of concrete. In this study, GGBFS was used at 10%, 20%, 30% of the cement weight, while fly ash was used at 10% of the cement weight. The water-cement (w/c) ratio was 0.5. The test results showed that a concrete mixture with 10% GGBFS and 10% fly ash achieved an optimal compressive strength of 50.10 MPa. This indicates that GGBFS and fly ash can be used as partial cement substitutes, with the optimum percentage being 10% for both materials. The result of the splitting test showed that concrete containing 10% GGBFS and fly ash achieved a high tensile strength of 5.06 MPa. The ratio of splitting tensile to compressive strength indicated that concrete containing GGBFS and fly ash had an average splitting tensile strength of 10–11%, indicating good tensile performance.***
*Keywords*—GGBFS; fly ash; cement; concrete; the compressive strength, splitting tensile strength

## I. INTRODUCTION

Concrete is commonly used for building construction. Concrete is produced using fine aggregate in the form of sand, coarse aggregate in the form of crushed stone, cementitious materials, and water as a binder. Currently, cement is produced using environmentally friendly raw materials or industrial by-products, such as fly ash. Fly ash is a waste by-product from coal combustion used by PLTU (coal-fired power plants) as an energy source, producing 80% fly ash and 20% bottom ash [1]. Fly ash contains dominant elements such as $SiO_2$ *(silica)* at 50.60%, $Al_2O_3$ *(aluminum oxide)* at 21.90%, $SO_3$ at 12.20%, and $Fe_2O_3$ at 7.76% [2]. Approximately half of the constituents in fly ash consist of $SiO_2$, which gives fly ash properties similar to cement, namely its ability to bind materials. The use of fly ash as a mixture for making concrete can also improve concrete strength. The addition of fly ash increases the silica ($SiO_2$) oxide component in cement, thereby increasing the amount of C3S and C2S compounds, which contribute to improving the compressive strength of cement and reducing cracking or expansion [3]. Fly ash can affect compressive strength due to its $SiO_2$ content, which acts as a filler, resulting in a denser matrix and thereby influencing the compressive strength of concrete [4].

This study combines GGBFS and fly ash because the cost of GGBFS is higher than that of fly ash. If concrete is made using cement with GGBFS, the production cost will be relatively high. Based on this consideration, this research was conducted by combining GGBFS and fly ash to determine the appropriate GGBFS percentage in the mixture to produce concrete that meets structural strength standards. Fly ash has been widely used as a concrete admixture and has been proven to improve workability during mixing and enhance concrete strength.

The research problem formulation in this study is as follows: 1) What percentage combination of GGBFS (Ground Granulated Blast Furnace Slag) waste at 0%, 10%, 20%, and 30%, with a fixed fly ash content of 10%, produces the optimum concrete strength?; 2) What is the highest splitting tensile strength of concrete using cement blended with GGBFS (Ground Granulated Blast Furnace Slag) and fly ash?; 3) Can a mixture of GGBFS (Ground Granulated Blast Furnace Slag) and fly ash be used as an alternative for partially replacing cement in concrete?

This study aims to investigate the behavior of concrete when cement is partially replaced with a combination of GGBFS and fly ash. The concrete strengths to be evaluated are compressive strength, to determine resistance to compressive forces, and splitting tensile strength, to assess resistance to tensile forces. It is expected that the results of this study will achieve the strong behavior of concrete using cement blended with GGBFS and fly ash. These results can serve as a reference for green concrete production technology using environmentally friendly cement and can be implemented by ready-mix concrete companies.

The study by Wahid & Taufan [5] investigated the use of GGBFS as an additive in mortar production, for a building material composed of a mixture of cement and sand. Variations of GGBFS at 0%, 2%, 4%, and 6% by weight of cement were used. A cement-to-sand ratio of 1 PC : 3 Sand was applied. The addition of GGBFS was found to improve plasticity, initial setting time, and mortar strength. The optimum GGBFS content was 6%, as the fresh mortar properties showed a 5% increase in plasticity, a 7.83% increase in setting time, along with a 6% increase in strength after hardening.

Previous research on the use of GGBFS was conducted by Arini et al. [6], who used GGBFS as a partial replacement for cement at percentages of 0%, 20%, 40%, and 60%. The concrete tests included compressive strength and fresh concrete properties, namely workability (slump test) and initial setting time. The mix design was developed using the DoE (Department of Environment) method. The optimum GGBFS content as a partial cement replacement was found to be 40%, at which the 28-day concrete achieved a compressive strength of 50.39 MPa. The results also showed that GGBFS in concrete mixtures increased slump values and delayed the initial setting time of cement. The highest increase in workability occurred at 60% GGBFS, with a slump value of 180 mm, and the initial setting time was longer by 30 minutes than the concrete without GGBFS.

This study combines GGBFS and fly ash because the cost of GGBFS is higher than that of fly ash. If concrete is made using cement with GGBFS, the production cost will be relatively high. Based on this consideration, this research was conducted by combining GGBFS and fly ash to determine the appropriate GGBFS percentage in the mixture to produce concrete that meets structural strength standards. Fly ash has been widely used as a concrete admixture and has been proven to improve workability during mixing and enhance concrete strength.

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The research problem formulation in this study is as follows: 1) How long does it take for the setting time of GGBFS and fly ash concrete?, 2) What percentage combination of GGBFS (Ground Granulated Blast Furnace Slag) waste at 0%, 10%, 20%, and 30%, with a fixed fly ash content of 10%, produces the optimum concrete strength?, 3) What is the highest splitting tensile strength of concrete using cement blended with GGBFS *(Ground Granulated Blast Furnace Slag)* and fly ash?, 4) Can a mixture of GGBFS (Ground Granulated Blast Furnace Slag) and fly ash be used as an alternative for partially replacing cement in concrete?

## II. Literature Review

Fly ash is a material that contains silica and alumina but does not possess cementitious properties (Fig. 1). However, in the presence of water, these compounds react with calcium hydroxide to form calcium silicate hydrate and calcium aluminate hydrate, which exhibit hydraulic properties. Fly ash is used in concrete mixtures and influences the properties of fresh concrete, namely: 1) improves workability due to the fine physical properties of fly ash, making the concrete more plastic and cohesive, 2) reduces bleeding because the fineness of fly ash lowers water demand, allowing better control of the water–cementitious ratio and reducing the potential for bleeding, 3) reduces the heat of hydration generated by $C_3A$ and $C_3S$ in the cement content, 4) increases compressive strength and strength development after 28 days, 5) provides resistance to sulfate attack, 6) enhances protection against corrosion and seepage. Concrete experiments were performed with the composition of Fly Ash 50% and 50% cement slag, which can made smaller production cost, and can help the need for development in the future [7]. The batching plants, which produce ready-mix concrete, have already used fly ash as a component in concrete mixtures to reduce cement consumption and to increase the compressive strength. They have not yet used a combination of fly ash together with GGBFS. If using GGBFS until 50% by weight of cement, the cost will be very high.

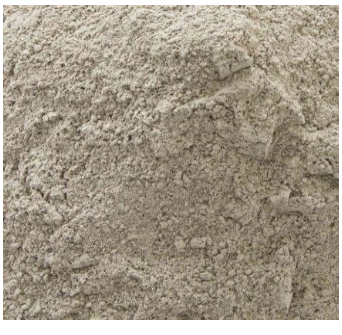

Figure 1. Fly ash from Tanjung Jati – Jepara, Central Java Province

Another waste material that has components similar to cement is GGBFS *(Ground Granulated Blast Furnace Slag)*. It is a combustion residue from a furnace during the steel refining process or a by-product of steel manufacturing, also known as slag cement (Fig. 2). Pozzolanic materials, which include industrial by-products from coal combustion, agricultural waste, and natural pozzolans, can be used as partial substitutes for cement due to their cement-like properties when added to cement mixtures. The use of these materials as a substitution for cement in concrete mixtures has been shown to improve workability and overall performance, both in high-strength and lower-strength concrete mixtures. GGBFS contains major elements such as calcium, aluminum, and silica, with a chemical composition similar to that of natural mineral materials, including hydration materials such as portland cement [6].

Figure 2. GGBFS (*Ground Granulated Blast Furnace Slag*)

The GGBFS used in this study is a waste by-product obtained from PT Krakatau Semen Indonesia (KSI), located in Cilegon, Banten, West Java. GGBFS contains $SiO_2$ *(silica)*, CaO, $Al_2O_3$, and MgO, which can be used as a partial binder to replace cement in concrete mixtures [8]. The chemical compounds contained in cement, GGBFS, and fly ash are presented in Table 1.

**Table 1.** The Chemical Compounds Contained in Cement, GGBFS, and Fly Ash

| No | Parameter | Cement | GGBFS | *Fly ash* |
|---|---|---|---|---|
| 1 | Silicon Dioxide ($SiO_2$) | 20.02 | 37.21 | 50.06 |
| 2 | AluminaTrioxide ($Al_2O_3$) | 5.5 | 15.16 | 20.78 |
| 3 | Ferric Trioxide ($Fe_2O_3$) | 3.27 | 0.69 | 2.85 |
| 4 | Calcium Oxide (CaO) | 64.63 | 42.85 | 5 |
| 5 | Magnesium Oxide (MgO) | 1.97 | 1.05 | 1.72 |
| 6 | Sulfur Trioxide ($SO_3$) | 1.98 | 1.98 | 1.32 |
| 7 | Loss On Ignition (LoI) | 3.52 | Less than 0.01 | 0.48 |

The use of Ground Granulated Blast Furnace Slag (GGBFS) as a partial replacement for cement is an effort to reduce carbon dioxide ($CO_2$) emissions during concrete production. When cement is mixed with slag, it alters the mineralogical distribution and surface electrical properties, increases tortuosity, and reduces porosity and critical pore size, thereby providing high chloride resistance and improved durability performance. In developed countries, the use of GGBFS in concrete has been widely adopted; however, in Indonesia, not all construction projects have implemented slag-based concrete [9]. The use of GGBFS as a partial cement substitute results in green concrete or environmentally friendly concrete. The GGBFS concrete reached its maximum compressive strength at 40% GGBFS and decreased at 45% GGBFS [10].

The study by Wahid & Taufan [5] investigated the use of GGBFS as an additive in mortar production, for a building material composed of a mixture of cement and sand. Variations of GGBFS at 0%, 2%, 4%, and 6% by weight of cement were used. A cement-to-sand ratio of 1 PC : 3 Sand was applied. The addition of GGBFS was found to improve plasticity, initial setting time, and mortar strength. The optimum GGBFS content was 6%, as the fresh mortar properties showed a 5% increase in plasticity, a 7.83% increase in setting time, along with a 6% increase in strength after hardening.

Previous research on the use of GGBFS was conducted by Arini et al. [11], who used GGBFS as a partial replacement for cement at percentages of 0%, 20%, 40%, and 60%. The concrete tests included compressive strength and fresh concrete properties, namely workability (slump test) and initial setting time. The mix design was developed using the DoE (Department of Environment) method. The optimum GGBFS content as a partial cement replacement was found to be 40%, at which the 28-day concrete achieved a compressive strength of 50.39 MPa. The results also showed that GGBFS in concrete mixtures increased slump values and delayed the initial setting time of cement. The highest increase in workability occurred at 60% GGBFS, with a slump value of 180 mm, and the initial setting time was delayed by 30 minutes compared to normal concrete (without GGBFS).

## III. Materials and Methods

Tests were conducted on the materials to be used in the mixture, namely sand (fine aggregate) and crushed stone (coarse aggregate), to determine whether the materials meet the required standards for use. The material test results showed that the sand and crushed stone met the eligibility requirements for use in concrete mixtures. Crushed stone with a diameter of 5–30 mm was used, zone 1 with an Fm of 7.23. The sand used was natural sand with a particle gradation in zone 2 and an Fm of 2.60. The research was conducted at the Concrete Laboratory of the Faculty of Engineering, UWKS, and at a partner laboratory, the Concrete Laboratory of PT Varia Usaha Beton.

In this research, cement is produced by PT. Semen Gresik. GGBFS waste was obtained from PT. Krakatau Semen Indonesia (KSI), located in Cilegon, Banten, West Java Province. Fly ash waste was sourced from the Tanjung Jati coal-fired power plant (PLTU) in Jepara, Central Java Province. The specific gravities of GGBFS and fly ash were found to be 2.53 and 2.25, respectively. GGBFS was used as a substitute for cement at variations of 10%, 20%, dan 30%, while fly ash was used 10% of the cement weight. Using GGBFS above 50% of the total binder volume may be inefficient, considering the higher percentage of GGBFS replacements [12]. The maximum addition of fly ash is 12,5% [13], and 10% [4]. Additive G was used in the mixture to improve workability. This study focuses on using GGBFS content; therefore, fly ash was used in only one variation.

Cement testing was also conducted by blending cement with GGBFS and fly ash. The cement tests included normal consistency and setting time tests, and the procedure refers to the SNI standard [14]. These tests were carried out to understand the behavior of the cement so that, during the concrete mixing process, the behavior of cement blended with GGBFS and fly ash could be anticipated, particularly whether hardening would occur faster or slower compared to cement without GGBFS and fly ash. The material mixture composition for the normal consistency test and setting time test is presented in Table 2. The amount of water used varied depending on the penetration of the Vicat needle. At the beginning of the test, a water content of 70 mL was used, and the Vicat needle penetration was observed. If the Vicat needle penetration exceeded 10 mm, the water content was reduced. Conversely, if the penetration was less than 10 mm, the water content was increased by approximately 5–10 mL from the initial 70 mL. The test was conducted three times. The resulting cement, GGBFS, and fly ash compositions and water contents were also used in the setting time tests.

**Table 2. The Material Composition for The Mix of Cement Paste**

| % GGBFS | % *Fly ash* | Semen (gram) | GGBFS (gram) | *Fly ash* (gram) |
|---|---|---|---|---|
| 0 | 0 | 250 | - | - |
| 0 | 10 | 225 | - | 25 |
| 10 | 10 | 200 | 25 | 25 |
| 20 | 10 | 175 | 50 | 25 |
| 30 | 10 | 150 | 75 | 25 |

In concrete production, the amount of water used greatly affects the strength behavior of concrete. Therefore, a mixed design is required to determine the composition of each material and the required water volume for the concrete mixture. In this study, the ACI method was used with a water–cement ratio (w/c) of 0.4. This was based on the findings of [9] which showed that the higher the GGBFS content, the lower the water demand.

The specimens were cylindrical with a diameter of 150 mm and a height of 300 mm. The specimens were cured in water to maintain their quality until testing age. The tests conducted included a slump test on fresh concrete while it was still in a fluid condition, using the Abrams cone. For hardened concrete, compressive strength tests were carried out at ages of 7, 14, and 28 days, and splitting strength tests were performed at 28 days. The test results were analyzed using formulas established by relevant standards to obtain the values of compressive and splitting strength, followed by observations and discussions to achieve the conclusion.

Table 3 shows the material requirements for the mixer in 1 $m^3$, and Table 4 shows those for GGBFS and fly ash. For each mixture variation and concrete age, three test specimens were prepared, as shown in Table 5. Each specimen was assigned a name or code to signify the percentage of GGBFS and fly ash used, to facilitate differentiation among specimens (Table 5).

**Table 3. Material Requirements 1m$^3$**

| Material | Weight (kg) |
|---|---|
| Cement | 459 |
| Sand | 727.65 |
| Crushed stone | 1008.49 |
| Water | 182.87 |

**Table 4. Cement, GGBFS, and Fly Ash Requirements for Specimen 1m$^3$**

| % GGBFS | % *Fly Ash* | Cement (kg) | GGBFS Requirements (kg) | Fly Ash Requirements (kg) |
|---|---|---|---|---|
| 0% | 0% | 459.00 | - | - |
| 0% | 10% | 456.84 | 10% x 459 x 0.057 = 2.16 | 2.16 |
| 10% | 10% | 454.68 | 10% x 459 x 0.057 = 2.16 | 2.16 |
| 20% | 10% | 452.53 | 20% x 459 x 0.057 = 4.31 | 2.16 |
| 30% | 10% | 450.37 | 30% x 459 x 0.057 = 6.47 | 2.16 |

**Table 5. Name and Code of The Specimen**

| Name and Code The Specimen | Material |
|---|---|
| G0F0RH | GGBFS 0% + Fly ash 0% + Additive tipe G |
| G0F10RH | GGBFS 0% + Fly ash 10% + Additive tipe G |
| G10F10RH | GGBFS 10% + Fly ash 10% + Additive tipe G |
| G20F10RH | GGBFS 20% + Fly ash 10% + Additive tipe G |
| G30F10RH | GGBFS 30% + Fly ash 10% + Additive tipe G |

To determine the strength capacity of each specimen, a compressive strength test was conducted by applying a compressive load to the concrete specimens until failure, thereby obtaining the maximum load that the specimens could withstand. The compressive strength of the concrete was determined from the stress value calculated using Eq. (1). The tests were carried out at ages of 7, 14, and 28 days to evaluate the development of strength increase or decrease. The testing procedure followed SNI standards [15].

$$f'c = \frac{P}{A} \tag{1}$$

with:

$f'c$ = compressive strength
$P$ = maximum load sustained by the specimen (N)
$A$ = the surface area of the loaded = $1/4\pi D^2$ ($mm^2$)

The splitting tensile test on hardened concrete aims to determine the tensile strength of concrete using cement blended with GGBFS and fly ash. Structurally, concrete has a weakness in withstanding tensile force. The splitting tensile strength of concrete is approximately 9%–15% of its compressive strength [16]. The compressive and tensile strength of concrete are not directly proportional; efforts to improve compressive strength are only accompanied by a relatively small increase in tensile strength [17]. The setting of the concrete splitting test is shown in Fig. 3.

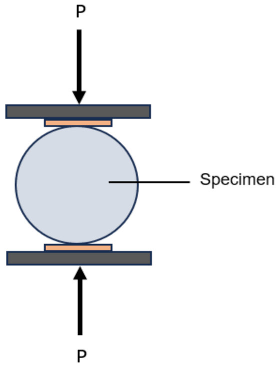


Figure 3. Set up a splitting test of concrete

The splitting tensile strength test was conducted in accordance with the procedure specified in SNI 03-2491-2002 [18] by placing the cylindrical concrete specimen horizontally and subjected compressive load until the concrete was crushed (Figure 5). The splitting tensile strength value was calculated using Eq. (2).

$$f_{ct} = \frac{2P}{\pi L D} \quad (2)$$

with:

$f$ct = Splitting tensile strength (MPa)
$P$ = Maximum load (N)
$L$ = Length of specimen (mm)
$D$ = Diameter of specimen (mm)

## IV. Result and Discussion

The setting time is required to determine how long the setting and hardening process of concrete takes, so that the duration of the concrete mixing process can be properly considered. The setting time test of cement paste with GGBFS and fly ash was approximately 12 minutes longer than that of cement paste without GGBFS and fly ash. Setting time is the period when the cement paste begins to harden. Hardening time is the period when the cement paste has completely hardened, as indicated by the Vicat needle being able to penetrate the paste. The hardening time test of cement paste with GGBFS and fly ash was about 15 minutes longer than that of cement paste without GGBFS and fly ash. This hardening time provides information on the duration required for the concrete mix to set, from mixing completion until hardening, which is 165 minutes. This information is very important during the preparation of concrete specimens, to ensure that the casting process does not exceed the hardening time. The process required to make the test specimens in this study took less than 60 minutes, so the concrete had not yet begun to harden. However, if concrete is produced at the batching plant so far from the casting location, the travel time and pouring process must be accounted for to ensure they do not exceed 165 minutes. The slump test result was approximately 110 to 120 mm, and the mean water content in the mixture was in accordance with the planned slump. The concrete mix using GGBFS and fly ash also met the planned slump, and workability posed no issues.

### *A. The Result of The Compressive Strength Test*

The result of the concrete compressive strength testing at ages 7, 14, and 28 days is presented in Table 5 and Fig. 4. Fig. 4 shows the compressive strength values for each specimen type from 7 days to 28 days. The specimen with GGBFS and fly ash obtained a compressive strength lower than that without GGBFS and fly ash (G0F0RH). Fig. 5(a) shows the specimen of G0F0RH testing. All of the specimens have an average increased 33% from 7 days to 28 days. The compressive strength of G10F10RH at 28 days is the highest value among the specimens, at 50.10 MPa. Fig. 5(b) shows the specimen of G10F10RH testing. Compared with concrete without GGBFS and fly ash (G0F0RH), the compressive strength of G10F10RH concrete was approximately 11.80% lower. The G30F10RH concrete had the lowest compressive strength with a much larger difference compared to G0F0RH, at around 37%. This indicates that the maximum percentage of GGBFS is recommended 10%, it is mixed with 10% fly ash to prevent a decrease in compressive strength.

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**Table 5. The Result of Compressive Strength**

| Specimen Code | Compressive strength *f'*c (MPa) | | |
|---|---|---|---|
| | **Age 7 Hari** | **Age 14 Hari** | **Age 28 Hari** |
| G0F0RH | 40.39 | 51.65 | 58.70 |
| G0F10RH | 32.23 | 39.65 | 49.67 |
| G10F10RH | 35.40 | 44.09 | 50.10 |
| G20F10RH | 27.21 | 33.46 | 41.87 |
| G30F10RH | 24.01 | 29.54 | 36.93 |

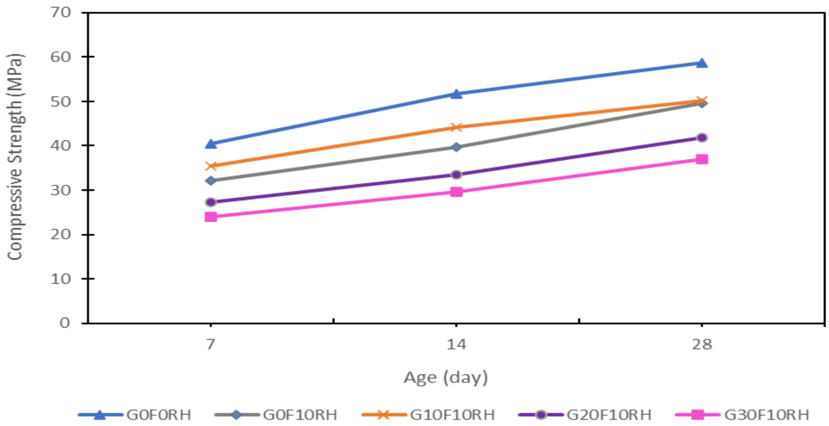


Figure 4. Compressive strength of the concrete specimen


(a)

(b)

Figure 5. Compressive strength testing of specimens of (a) G0F0RH; (b) G10F10RH

Based on the compressive strength value, increasing the percentage of GGBFS in the concrete mixture can reduce compressive strength. The *Calcium Oxide* (CaO) content in GGBFS, according to the Report of Analysis data (Table 1), is 42.85%. This contributes to the decrease in concrete compressive strength because the CaO content in GGBFS is relatively low, whereas CaO functions as a binding agent. In comparison, the *Calcium Oxide* (CaO) content in cement is higher than that in GGBFS, at 64.63%. This is one of the factors decreasing compressive strength when GGBFS is used at levels above 10%. The CaO, $SiO_2$ components, and the finest cement will increase the compressive strength of the

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mortar [19]. At 28 days, the concrete specimen without GGBFS and with 10% fly ash (G0F10RH) reached a lower compressive strength than G10F10RH, by approximately 4.30%. This indicates that GGBFS has affected the strength of concrete.

## *B. The Result of The Splitting Tensile Strength Test*

The result of the splitting tensile test on concrete specimens is shown in Table 6 and Fig. 6. The splitting tensile test aims to obtain information on the tensile stress properties of concrete using GGBFS and fly ash. It is known that concrete is weak in resisting tensile force. Fig. 6 shows that at 28 days, the highest splitting tensile strength value was reached for G0F0RH, 5.34 MPa. The G10F10RH has the highest splitting value among the other specimens with a mixture of GGBFS and fly ash, namely 5.06 MPa, which is 5.24% lower than concrete without GGBFS and fly ash (G0F0RH). Fig. 7 shows the splitting tensile specimens testing of G0F0RH and G10F10RH.

**Table 6. The Result of Splitting Tensile**

| Specimen Code | Splitting Tensile, *ft* (MPa) |
|---|---|
| | Age 28 Hari |
| G0F0RH | 5.34 |
| G0F10RH | 4.98 |
| G10F10RH | 5.06 |
| G20F10RH | 4.50 |
| G30F10RH | 4.06 |

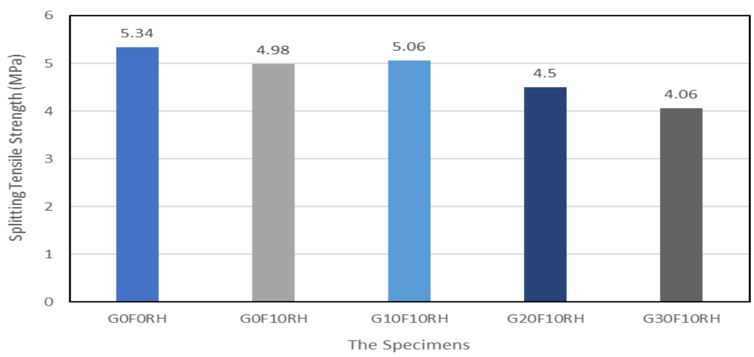


Figure 6. The splitting tensile strength value of the specimen

(a) (b)

Figure 7. Splitting tensile testing of specimens of (a) G0F0RH; (b) G10F10RH

The result of the splitting tensile strength test indicated that the GGBFS concrete has the ability to withstand tensile stress, and GGBFS significantly influences the behavior of concrete in resisting tensile stress. As the percentage of GGBFS used in the mixture increases, the splitting tensile strength decreases. The concrete with the lowest splitting tensile strength was G30F10RH, at 4.06 MPa, approximately 1.25% lower than that of G0F0RH concrete.

### *C. The Ratio of Splitting to Compressive Strength Value*

Splitting strength of concrete is approximately 9 to 15% from its compressive strength [16]. The relationship between the value of compressive strength and tensile stress is not linear; improving compressive strength results in only a slight increase in tensile strength [19]. Based on this, the ratio of the splitting tensile to compressive strength of concrete using GGBFS and fly ash is approximately 10% to 11% (Table 7 and Fig. 8). This indicates that the concrete containing GGBFS and fly ash has good performance in terms of its ability to withstand tensile stress, with it being known that a tensile strength ratio to compressive strength of approximately 9% to 15%. The splitting tensile strength is not directly proportional to the compressive strength. Concrete containing GGBFS and fly ash has a higher splitting tensile strength than that of concrete without GGBFS and fly ash (G0F0RH), and the G30F10RH concrete has the highest ratio among the other concretes.

**Table 7. Ratio of Splitting Tensile to Compressive Strength Concrete**

| Specimen | Splitting Tensile *ft* (MPa) | Compressive Strength *f'c* (MPa) | Rasio (%) |
|---|---|---|---|
| G0F0RH | 5.34 | 58.70 | 9.10 |
| G0F10RH | 4.98 | 49.67 | 10.03 |
| G10F10RH | 5.06 | 50.10 | 10.10 |
| G20F10RH | 4.50 | 41.87 | 10.75 |
| G30F10RH | 4.06 | 36.93 | 11.00 |

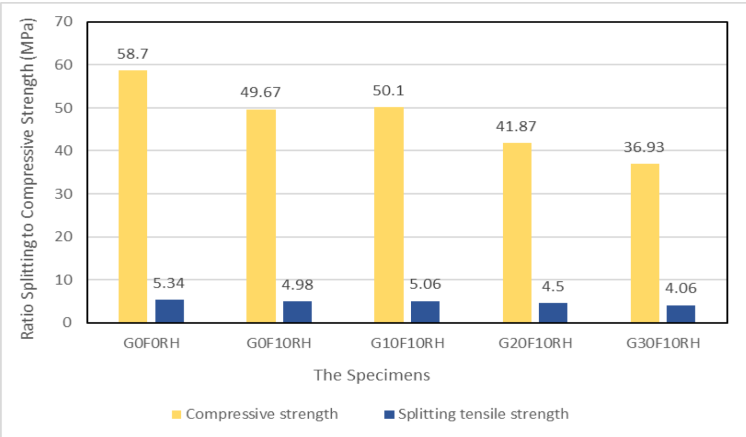


Figure 8. The splitting tensile and compressive strength values

## V. Conclusion

From the test results and discussion of concrete mixed with Ground Granulated Blast Furnace Slag (GGBFS) and fly ash, several conclusions can be drawn as follows:

The setting time and hardening of cement paste with GGBFS and fly ash were approximately 12 minutes and 15 minutes longer, respectively, than those of cement paste without GGBFS and fly ash.

The maximum GGBFS content that can be used as a concrete admixture with 10% fly ash is 10%. If the GGBFS content exceeds 10%, the compressive strength will decrease due to the low CaO content in GGBFS and fly ash, which function as binding agents.

The concrete containing 10% GGBFS and 10% fly ash achieved the optimum compressive strength of 50.1 MPa at 28 days, the highest value compared to the other concretes; however, it was approximately 11.80% lower than that of concrete without GGBFS and fly ash.

The concrete containing 10% GGBFS and 10% fly ash achieved the optimum splitting tensile strength of 5.06 MPa at 28 days, which was the highest value compared to the other concretes; however, it was 5.24% lower than that of concrete without GGBFS and fly ash.

The concrete containing GGBFS and fly ash can withstand tensile stress; based on the result of the splitting test, the ratio of splitting tensile to compressive strength is approximately 10-11%.

## Author Contributions

U.K. conceptualized the study, supervised the research process, and coordinated the overall research activities. S.P.M., A.A., and E.S contributed to the research process and evaluation results. All authors contributed to manuscript preparation, critically reviewed the content, and approved the final version of the manuscript.

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