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The Influence of Cement Type on Seawater-Affected Concrete Impermeability

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ABSTRACT

The impermeability of concrete exposed to seawater is key in maintaining long-term structural integrity. In an exposed environment, concrete must be able to protect itself from seawater penetration which can potentially cause damage, corrosion and material degradation. This study aims to investigate the effect of different types of cement on the impermeability of concrete using Ground Granulated Blast-furnace (GGBFS) as concrete filler based on gradation to obtain dense concrete, especially when exposed to seawater during the maintenance period with age variations of 7, 28, and 56 days. Three types of cement available in the general public were used, namely, type V, Portland Composite Cement (PCC), Portland Pozzolan Cement (PPC). The research method used was experimental testing with 6 variations with the dimensions of a cylinder measuring 15x15x30 cm ^{3} and a cube measuring 15x15x15 cm^3. The results obtained in the form of compressive strength test with the highest elastic modulus is cement type V GGBFS of 48.12 MPa with elastic modulus 38153.21 MPa while the smallest is Portland Pozzolan Cement (PPC) 35.93 MPa and 26339.61 MPa for elastic modulus. In this study, concrete mixes with Ground Granulated Blast Furnace Slag (GGBFS) showed a significant increase in compressive strength over time, despite initially having lower strength than regular cement mixes. The use of GGBFS in concrete offers long-term benefits, with the potential to achieve higher compressive strengths. This study demonstrates the importance of considering treatment time and the use of GGBFS in designing more durable and robust concrete mixes.

1 Introduction

Indonesia is an archipelago with a long coastline, and a lot of construction is carried out in coastal areas and at sea. This poses a major challenge in maintaining durability due to various factors. One of the main concerns is the corrosion of reinforcing steel in concrete structures [1]. Exposure to aggressive marine environments, such as seawater, is known to accelerate the corrosion process, affecting the long-term service life of structures such as port and coastal defense facilities [2]. Chloride attack, a common problem in marine and coastal areas, is a major factor affecting the durability of reinforced concrete structures [3]. The porous nature of concrete is another critical aspect that affects durability, especially in harsh exposure conditions such as marine environments [4]. The water to cement ratio plays an important role in the durability of concrete structures, emphasizing the importance of proper mix design and construction practices [5]. In addition, concrete degradation in offshore environments can be accelerated by factors such as chemical attack, abrasive wave action, and microorganism attack [6].

To overcome these challenges, various strategies have been proposed. One effective solution is to make impermeable concrete with minimal gaps and pores to prevent seawater penetration. The use of cements with lower levels of C_3A and C_4AF can reduce the formation of calcium aluminate hydrates and, in turn, reduce the damaging chemical reactions during cement hydration. Additionally, the addition of active pozzolanic additives, such as ground granulated blast furnace slag (GGBFS), is highly recommended as it can improve concrete performance. GGBFS is an amorphous by-product of the steel industry and is commonly used as an additive in concrete mixes. GGBFS typically replaces 35% to 65% of Portland cement in concrete mixes [7]. It is known to have latent hydraulic properties and can improve the chemical resistance of concrete, making it a valuable ingredient in concrete production [8]. GGBFS has been found to make the structure of hardened cement paste more compact, reduce porosity, and increase impermeability, which can improve the durability of concrete in various environments [9].

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Studies show that the addition of GGBFS can affect the compressive strength of concrete mixtures. Although GGBFS can exhibit similar characteristics to concrete with ordinary Portland cement content at certain replacement levels, there is evidence of a decrease in compressive strength with increasing GGBFS content in the concrete mix [10]. Factors such as delayed strength development, reduced workability, and interaction of GGBFS with other materials in the mix may contribute to this reduction in compressive strength. In addition, the chemical composition of GGBFS, including the presence of Al_2O_3, can affect its hydration properties and reactivity in concrete mixes [10]. The particle size of GGBFS has also been shown to affect fracture toughness, critical stress intensity, and strength of concrete [11]. Furthermore, the fineness of GGBFS, indicated by its specific surface area, can affect the compressive strength and hydration activity index at different curing ages [12].

In conclusion, GGBFS is a versatile material that can improve the properties of concrete mixtures. However, its impact on compressive strength may vary depending on various factors such as replacement level, curing conditions, mix proportions, and chemical composition. Understanding these factors is critical to optimize concrete mix design when incorporating GGBFS to achieve the desired strength properties.

Based on research, the use of 40% ground granulated blast furnace slag (GGBFS) in concrete mixes has been shown to produce an optimum compressive strength of 50.39 MPa. This percentage was identified as the critical point for achieving high compressive strength in various studies. For example, researchers reported that replacing up to 40% of cement with GGBFS can improve compressive strength, with satisfactory results even at replacement levels up to 60% [13]. Additionally, it was found that GGBFS can effectively replace up to 50% of cement while maintaining compressive strength comparable to conventional concrete [14].

Comparing the compressive strength of concrete mixtures with different compositions, it is clear that the use of 40% GGBFS stands out in achieving optimal strength. For example, a study found that the compressive strength of concrete increased significantly with the addition of GGBFS, with the highest strength values observed in mixes containing 40-50% GGBFS [15]. In addition, the addition of GGBFS has been shown to improve the long-term compressive strength of concrete, with a significant increase after 28 days of treatment [16]. On the other hand, studies have also explored the impact of different proportions of GGBFS on compressive strength. For example, while the use of 50% GGBFS resulted in a compressive strength of 24.8 MPa in one study [17], another study showed that mixtures with 100% GGBFS replacement achieved a maximum compressive strength of 78.25 MPa at 7 day [18] s .

This research was conducted to investigate how concrete mix composition, including the use of GGBFS, affects the seawater impermeability of concrete. By understanding the factors that affect concrete impermeability, such as the ratio of cement types, and the addition of additives such as GGBFS, the construction industry can design concrete mixes that are more resistant to seawater penetration and corrosion. As a practical solution, the use of GGBFS at optimal levels, such as 40%, can help improve concrete impermeability as well as compressive strength, creating more durable and sustainable coastal and marine infrastructure. As such, this research provides valuable insights for the construction industry in designing coastal and marine infrastructure that can withstand exposure to harsh environments such as seawater, thereby extending service life and reducing long-term maintenance costs.

2 Methods

The research began by delving into the literature to gather information on various materials and the effects of relevant variables in the manufacture of concrete mixes. As a guide, the research referred to clearly documented testing standards, as listed in Table 1. Experimental methods were carried out at the Civil Engineering Materials Laboratory of Universitas Gadjah Mada and LPPT Universitas Gadjah Mada, ensuring consistency and reliability of the testing procedures.

Table 1. Testing Standard

No.	Testing	Standar
1	Unit weight of aggregate	SNI 03-4804-1998
2	Aggregate sieve analysis	SNI 03-2834-2000
3	Specific gravity of coarse aggregate	SNI 1969:2008
4	Specific gravity of fine aggregate	SNI 1970:2008
5	Aggregate mud content	SNI 03-4142-1996
6	Organic content	SNI 2816:2014
7	Concrete specific gravity testing	SNI 03-1974-1990
8	Air voids testing	SNI 03-6333-2000
9	Concrete compressive strength testing	SNI 03-1974-2011; ASTM C 136
10	Permeability testing	SNI 03-4810-1998; DIN 1048

The preparation of the study involved the provision of tools and materials required for the experiments. Material testing included aggregate characterization, XRF (X-Ray Fluorescence) analysis of Ground Granulated Blast Furnace Slag (GGBFS), and the use of SEM (Scanning Electron Microscope) techniques to observe the microstructure of the concrete. This was an important first step in understanding the nature of the material to be used in the concrete mix, as well as to evaluate the chemical composition and morphology of GGBFS in detail.

As such, this approach allowed the researcher to have a solid foundation before moving on to the next stage of the experiment, ensuring that all relevant variables were considered and the test procedure was well prepared. These steps are important to ensure the accuracy and reliability of the data to be collected during the experiments.

2.1 Research materials

This study explores the use of local materials in concrete production in Indonesia, including Ground Granulated Blast Furnace Slag (GGBFS) from PT Krakatau Semen Indonesia, fine aggregate from Merapi, Yogyakarta, and 20 mm coarse aggregate from Clereng, Yogyakarta supplied by CV Muncul Karya Yogyakarta. In addition, PPC, V, and PCC cements from PT Semen Indonesia, Gresik, were used as additional binders. Resistance tests against chloride ion penetration using a 10 M silver nitrate ($AgNO_3$) solution were conducted to measure the penetration and corrosive effects on the concrete. This research shows that the use of these local materials can improve the performance of concrete in construction applications by meeting technical standards and supporting sustainability principles in the development of environmentally friendly infrastructure.

2.2 Research equipment

The study required the use of a variety of specialized equipment that is at the core of testing and evaluating the technical properties of concrete. A concrete mixer with a capacity of 0.5 m^3 was the main equipment used to mix the concrete ingredients homogeneously, ensuring that the concrete mix had an optimal consistency before the casting process began. A set of SNI 03-1968-1990 standard sieve is used to test the gradation of coarse and fine aggregates, which is very important to ensure that the aggregate composition meets the set technical requirements, such as appropriate size distribution.

A slump cone is a tool used to measure the consistency of fresh concrete, which is an important parameter in determining the ease of casting and ensuring that the concrete can maintain its shape according to the expected standard. An ELE brand Angeles Loas machine was used to test the coarse aggregate's resistance to wear, which gives an idea of how well the aggregate can resist abrasion and maintain its strength in concrete applications.

Digital scales were used to weigh the concrete ingredients with a high degree of accuracy, ensuring that the proportions of the concrete mix were maintained exactly according to the planned design. A 0.05 mm precision caliper was used to accurately measure changes in the dimensions of the test specimens, which is important for obtaining consistent data in testing.

The Universal Testing Machine (UTM) is the main equipment used to test the compressive strength and modulus of elasticity of concrete, providing information on the concrete's resistance to stress and its ability to stretch. This equipment not only ensures that the concrete produced meets stringent quality standards for construction applications, but also supports the vision of sustainable and efficient infrastructure development in the long term.

2.3 Research stages

2.3.1 Material testing

Material testing is carried out for all concrete constituent materials, namely (1) Fine aggregate Characteristic Test, (2) XRF test of GGBFS, (3) Characteristic test of coarse aggregate.

2.3.2 Design of concrete composition

The manufacture of normal concrete mixtures is carried out manually in accordance with the SNI 03: 2834: 2000 standard, with a target strength of 35 MPa. The type of cement available is selected and the cement water factor (FAS) is obtained based on the compressive strength target of 0.393, this shows that the fas meets the standard not exceeding the optimal limit specified, namely 0.45. The number of materials used can be seen in Table 2.

Table 2. Proportional concrete mix 1 m^3

Cements (kg)	Water (kg)	Agregate		GGBFS (kg)
		fine (kg)	coarse (kg)	
Theoretical mix proportion Aggregate condition (SSD)				
343.860	205.000	582.006	1131.995	229.240
Mix proportion with shrinkage rate (10%)				
378.246	225.500	640.206	1245.194	252.164

3 Result and Discussion

3.1 Testing aggregate characteristics

In this study, fine aggregates from Merapi, Yogyakarta, were used, and the coarse aggregates used ranged from 10 to 20 mm, as can be seen in Figure 1 and Table 3.

Table 3. Characteristics of fine and coarse aggregates

Characteristics	Fine aggregate	Coarse aggregate	Standart
Gradations	Zone 3	Dia maks. 10 mm	SNI 03-1968-1990
Modulus of fine grain	2.27	6.86	
Unit weight of solid condition	1049.717 kg/m^3	1469.67 kg/m^3	SNI 03-4804-1998
Unit weight of Loose condition	1012.606 kg/m^3	1294.29 kg/m^3	
Specific gravity dry condition	2.623	2.540	SNI 1969:2008 (Coarse)
Specific gravity SSD conditions	2.712	2.619	SNI 1970:2008 (Fine)
Organic Content	Qualified	-	SNI 2816:2014
Silt Content	1.37 % (<5%)	-	SNI 03-4142-1996
Abrasion	-	20.66% < 27%* *untuk *f'c* > 20 MPa	SNI 2417:2008; SII 0052-80/SK-SNI. S-0401989

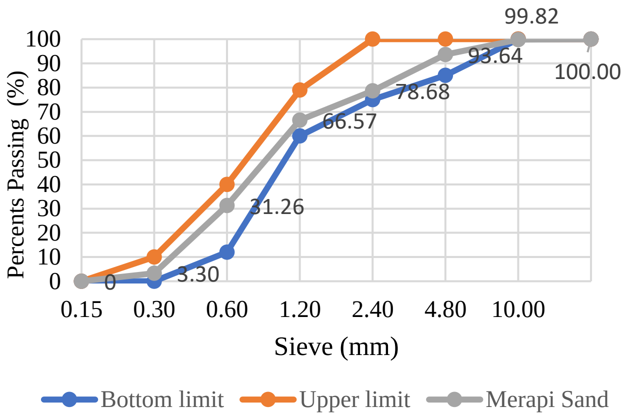

Figure 1. Fine Aggregate Gradation zone III

Table 4. Chemical components of GGBFS (%)

Components	Results (%)
Al_2O_3	15.45
SiO_2	36.52
Fe_2O_3	0.98
CaO	44.38
MgO	1.73
MnO	0.12
K_2O	0.33
Na_2O	0.16
LOI	0.18

3.2 Characteristic and microstructure testing of GGBFS material

In this study, the characteristics and microstructure of the GGBFS material used as a concrete mix were tested. XRF analysis was performed to identify the percentage of oxides contained in GGBFS, the results of which are listed in Table 4.

Based on the British standard BS EN 197-1:2000, it can be concluded that GGBFS should have a mass ratio of more than 1.0 shown in eq 1.

$$\frac{C_aO + M_gO}{S_iO_2O} \quad (1)$$

Based on ASTM C989/C989M - 18a Slag Activity Index In the standard, it falls into grade 120 indicating that the material has a binding strength of 120% of the reference strength used in the test. In general, GGBFS is divided into grades based on its strength it has very high reactivity and binding ability, making it very effective in improving the strength and durability of concrete.

3.3 Concrete compressive strength testing results

It is an important aspect of evaluating the quality of concrete used in various construction projects. This testing process involves applying a compressive load to a concrete sample until it reaches the point of failure, which provides information on how strong the concrete structure is in resisting pressure. Based on concrete compressive strength testing data on various cement type mixtures and testing ages of 7, 28, and 56 days, the following can be seen in Figure 2.

Based on the results of the compressive strength tests on the normal cement mix and the mix with Ground Granulated Blast Furnace Slag (GGBFS), there was a significant difference in the development of compressive strength over time. On day 7, the normal cement mix achieved an average compressive strength of 36.31 MPa, while the mix with GGBFS recorded a lower value of 26.55 MPa. This difference indicates that at the initial stage, the mix with GGBFS had lower strength compared to the normal cement.

However, the development of compressive strength in the mixtures with GGBFS showed a more significant increase on days 28 and 56. On day 28, the mix with GGBFS reached a compressive strength of 37.57 MPa, while the normal cement mix only reached 44.86 MPa. On day 56, the compressive strength of the mix with GGBFS increased further to 48.12 MPa, while the normal cement mix only slightly increased to 45.37 MPa. This indicates that although the mix with GGBFS initially had a lower compressive strength, over a longer period of time, it was able to reach and even exceed the compressive strength of the normal cement mix.

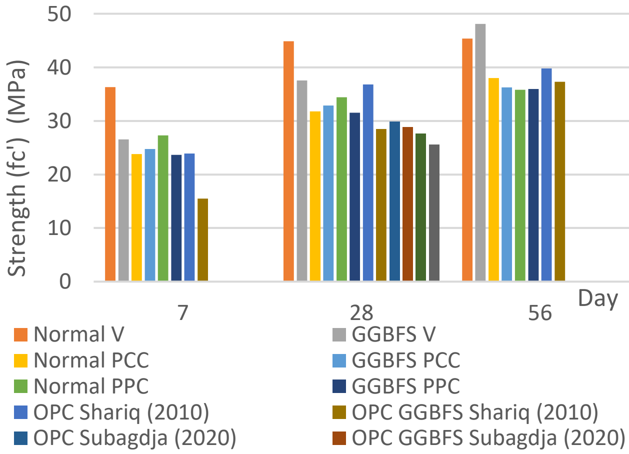

Figure 2. Compressive Strength

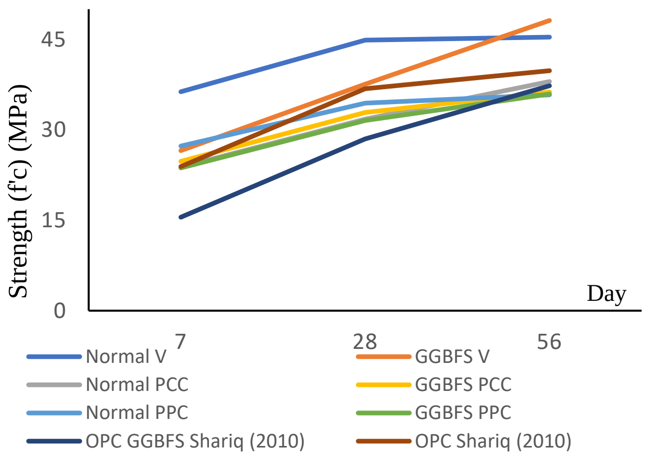

Figure 3. *Trendline* comparison strength (MPa)

Time-based analysis showed that both types of mixes experienced an increase in compressive strength over time, with a more significant increasing trend in the mixes with GGBFS. This indicates that the mix with GGBFS takes longer to reach its maximum strength. However, the end result shows that the use of GGBFS in concrete mixes provides benefits in the long term, with the potential to achieve higher compressive strengths compared to normal cement mixes.

In a previously conducted study by Subagja [19], substitution of GGBFS in OPC cement between 30-40% resulted in an optimum compressive strength of 28.91 MPa at 28 days of age. This study showed that the substitution of GGBFS in PPC cement produced a higher compressive strength of 31.53 MPa. These results indicate that the use of GGBFS PPC cement provides a significant increase in the compressive strength of concrete compared to previous studies.

In addition, another study by Shariq [20] that compared GGBFS substitution between 20-60% and cement water factor with plain water treatment, found that the maximum compressive strength at 28 days was 28.5 MPa, which is lower than the value obtained in this study. However, at 56 days, the compressive strength value reached 37.3 MPa, slightly higher than that of this study for both normal cement and GGBFS admixtures. These results indicate an increase in compressive strength as the concrete ages.

In a study conducted by Afif [21], who investigated the effect of tidal seawater with immersion times of 24 hours, 12 hours, and 8 hours on compressive strength, with variations in PCC cement substitution between 0-60%, it was found that the compressive strength with 40% GGBFS admixture was 25.57 MPa. It shows that Afif's results resulted in a lower compressive strength compared to all other studies, including the research conducted in it.

Analysis based on the trendline given by the compressive strength testing with seawater treatment has similarities with the research by Shariq [20] can be seen in Figure 3 where the use of certain levels of GGBFS has a constant increase as the age of the concrete increases and shows a slower increase in compressive strength at the beginning (7 days), but gives better or equal results at 28 days and 56 days, while the compressive strength with normal cement mixture tends to have a higher compressive strength at the beginning (7 days) but does not show a significant increase after 28 days. This indicates that the hydration process in normal concrete and concrete with GGBFS shows significant differences that affect the strength and durability of the concrete.

In normal concrete, hydration starts quickly when water is added to the mix, where tricalcium silicate (C_3S) reacts with water to form calcium silicate hydrate (C-S-H) and calcium hydroxide ($Ca(OH)_2$), providing significant initial strength. Calcium silicate (C_2S) reacts more slowly, contributing to long-term strength, while tricalcium aluminate (C_3A) forms etringite which controls the binding time. In contrast, concrete with GGBFS experiences slower hydration in the early stages because GGBFS reacts more slowly with water. However, GGBFS reacts with $Ca(OH)_2$ produced during the hydration of Portland cement, producing more C-S-H, which increases the strength and density of concrete in the long run. Concrete with GGBFS has a lower initial strength but shows a greater increase in strength over time and has better durability due to the reduction of free calcium hydroxide and improved resistance to chemical attack. In addition, concrete with GGBFS produces a lower heat of hydration, which is important for mass concrete applications.

3.4 Stress-strain Result

Stress-strain tests were conducted on several types of cement, including V Normal, V GGBFS, PCC Normal, PCC GGBFS, PPC Normal, and PPC GGBFS, each of which was tested with three variations (A, B, C). The results of these tests showed significant differences in maximum stress and maximum strain between the different types of cements tested as can be seen in the following Figure 4, 5, and 6.

Based on the stress-strain curves Figure 4 tested at 7 days, it was found that the maximum stress occurred in type V cement with a value of 36.31 MPa and a strain of 0.25%. In contrast, the lowest stress was recorded in GGBFS PCC, which was 23.82 MPa, although the strain was higher than normal concrete, reaching 0.34%. The effect of GGBFS in the cement mix had a significant impact on the stress-strain observed in type V cement and PCC, reaching 0.25% and 0.34%, respectively.

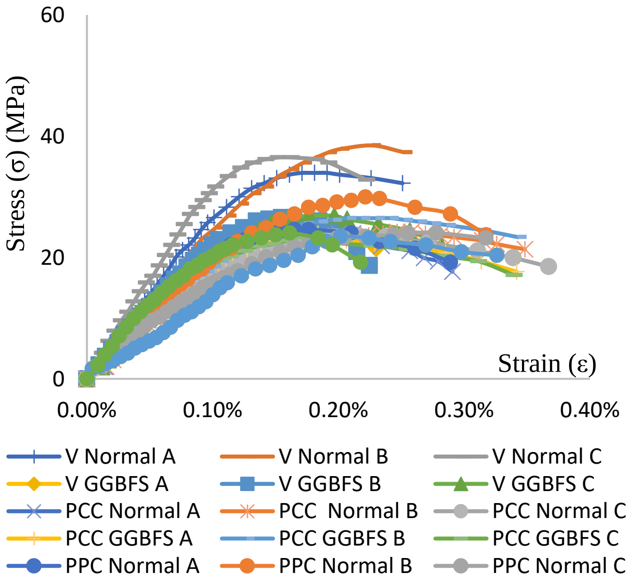

Figure 4. Stress-strain curve

At 28 days, the stress-strain curve Figure 5 showed the highest stress in type V cement at 44.86 MPa with a strain of 0.24%, while the lowest stress occurred in PPC cement at 31.53 MPa with a strain of 0.20%. This data shows that the use of GGBFS increases the stress-strain as the age of the concrete increases. This increase occurred in type V and PPC cements using GGBFS, which showed higher stress-strain results compared to ordinary cements.

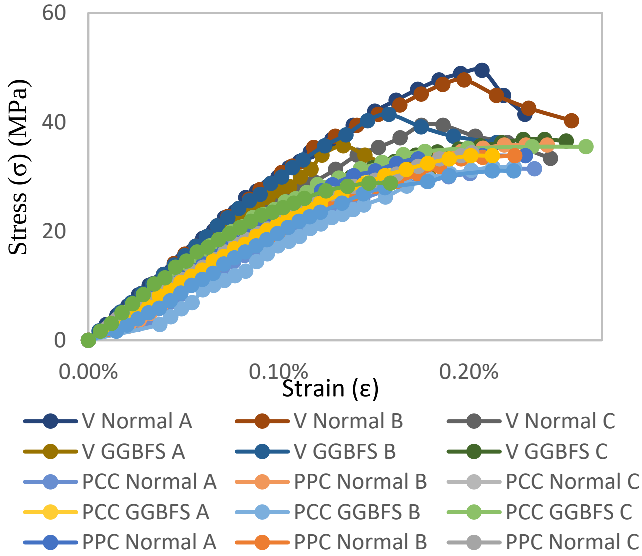

Figure 5. Stress-strain curve

At the age of 56 days, the highest stress-strain curve Figure 6 occurred in the GGBFS type V cement mix with a stress of 48.12 MPa and a strain of 0.18%, while the lowest stress-strain curve occurred in the PPC cement with a stress of 35.79 MPa and a strain of 0.18%. At 56 days, it can be seen that the effect of GGBFS on stress continues to increase, but the strain is not too different from normal cement. This indicates that GGBFS contributes significantly to the increase in concrete stress, although its impact on strain is not very noticeable. Thus, the use of GGBFS in cement mixes not only increases the compressive strength of concrete, but also maintains almost the same elasticity as normal cement, making it an efficient choice for constructions that require high strength and excellent durability.normal cement.

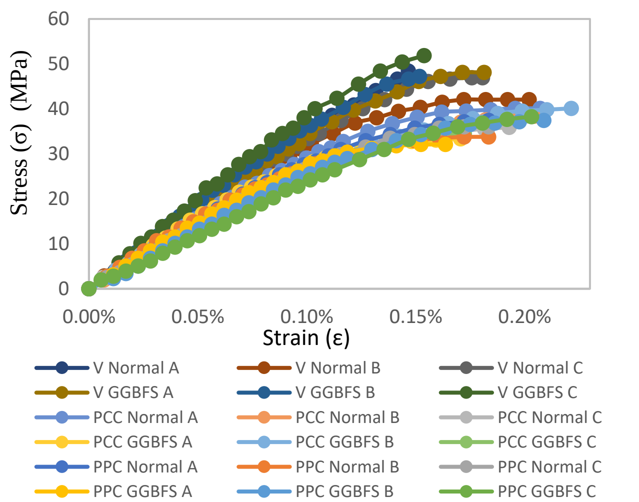

Figure 6. Stress-strain curve

3.5 Elasticity Modulus Test Results

The modulus of elasticity is an important parameter in determining the performance of concrete and reflects the stiffness of the material, or the extent to which the material can undergo elastic deformation under load. Generally, there is a correlation between compressive strength and elastic modulus: concrete with higher compressive strength tends to have a higher elastic modulus, as can be seen in Figure 7 of diagram below.

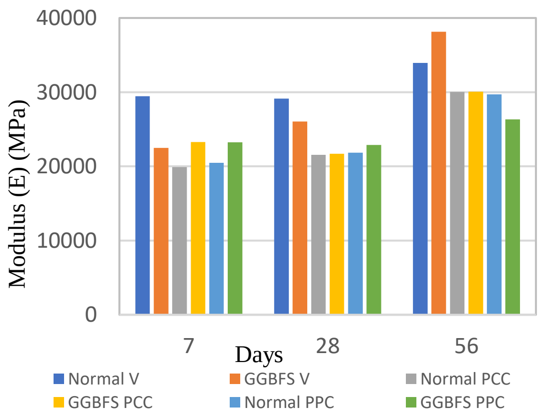

Figure 7. Modulus of elasticity

The charts show the modulus of elasticity values of different types of concrete materials at 7, 28 and 56 days of age. At 7 days, normal cement type V had the highest elastic modulus value of 29,473.03 MPa, indicating higher stiffness than other cement types. GGBFS type V blended cement had an elastic modulus of 22,477.93 MPa, which was lower than that of type V normal cement. PCC normal cement showed the lowest elastic modulus value of 19,904.81 MPa. Meanwhile, GGBFS PCC blended cement had an elastic modulus value of 23,268.97 MPa, higher than PCC normal cement and close to the value of GGBFS type V blended cement. PPC normal cement had an elastic modulus value of 20,484.74 MPa, higher than PCC normal cement but lower than GGBFS PCC blended cement. Finally, GGBFS PPC blended cement showed an elastic modulus value of 23,247.27 MPa, almost the same as GGBFS PCC blended cement and higher than PCC normal cement. From this data, it can be concluded that the use of GGBFS in cement mixes generally increases the modulus of elasticity compared to normal cement, except in type V where type V normal cement shows the highest modulus of elasticity value.

At 28 days, the graph shows that Normal V concrete has the highest elastic modulus of 29148.37 MPa, while Normal PCC concrete has the lowest elastic modulus of 21574.17 MPa. Substitution of Ground Granulated Blast Furnace Slag (GGBFS) in concrete generally decreases the elastic modulus value, except in concrete with PPC material, where substitution of GGBFS increases the elastic modulus value from 21860.87 MPa to 22896.04 MPa. This shows that the variation of additives and substitutes in concrete has a significant impact on the mechanical properties of concrete, especially in terms of modulus of elasticity.

At 56 days, concrete with GGBFS V had the highest elastic modulus of 38153.21 MPa, while concrete with GGBFS PPC had the lowest elastic modulus of 26339.61 MPa. At this age, the addition of GGBFS generally resulted in different variations in the elastic modulus values of each concrete type. For example, GGBFS substitution in Normal V concrete increased the elastic modulus from 33949.27 MPa to 38153.21 MPa, but in PPC concrete, GGBFS substitution decreased the elastic modulus from 29702.56 MPa to 26339.61 MPa. From these results, it can be concluded that the effect of GGBFS substitution on the modulus of elasticity of concrete differs depending on the type of base material used, which indicates that the variation of additives and substitutes in concrete greatly affects the mechanical properties of the concrete.

4 Conclusions and Suggestions

Based on the compressive strength test results, the cement mix with Ground Granulated Blast Furnace Slag (GGBFS) showed excellent performance in the development of concrete strength over time. At 7 days, the GGBFS mix recorded a compressive strength of 26.55 MPa, while normal cement reached 36.31 MPa. Although initially lower, by 28 days, the GGBFS mix had improved significantly to 37.57 MPa, close to the compressive strength of normal cement which reached 44.86 MPa. At 56 days, the mix with GGBFS recorded a peak compressive strength of 48.12 MPa, exceeding that of normal cement at 45.37 MPa. These results show that the use of GGBFS in cement mixes effectively increases the strength of concrete in the long term, making it an optimal choice for construction applications that require high durability and structural strength. Based on the data of elastic modulus values of various types of concrete materials at 7, 28, and 56 days, two main conclusions can be drawn as follows:

The substitution of Ground Granulated Blast Furnace Slag (GGBFS) in concrete mixes has different effects on the modulus of elasticity depending on the type of base cement used. In some concrete types, such as Normal V, GGBFS substitution increases the modulus of elasticity (clearly visible at 56 days with an increase from 33949.27 MPa to 38153.21 MPa). However, in other concretes such as PPC, GGBFS substitution decreased the elastic modulus (decreased from 29702.56 MPa to 26339.61 MPa at 56 days). This indicates that the effect of GGBFS on the mechanical properties of concrete is highly dependent on the initial composition of the concrete.

The modulus of elasticity of concrete changes as the age of concrete increases. At 28 days, concrete with Normal V exhibited the highest elastic modulus (29148.37 MPa), but at 56 days, concrete with GGBFS V had the highest elastic modulus (38153.21 MPa). These changes indicate that increasing concrete age can affect the stiffness and strength of concrete, and the effect of additives such as GGBFS can become more significant or change over time. This is important to consider in the design and long-term evaluation of concrete structures.

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