

PERFORMANCE OF CONCRETE MIXED WITH VOLCANIC ASH AND BUKHO STONE FRACTIONS

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ABSTRACT: To produce good-quality concrete and reduce dependence on commonly used materials, it is essential to support advanced materials that are abundantly available around the infrastructure development project. Volcanic waste materials, specifically volcanic ash as a substitute material for cement and bukho stone fractions as a local aggregate substitute, can be considered alternative concrete materials. This research aims to determine the optimal ratio of a mixture of volcanic ash and bukho stone fractions required to produce concrete with excellent compressive strength. The combination of volcanic ash and bukho stone fractions at 0%, 5%, 10%, 15%, and 20%, respectively. The compressive strength test specimens consist of cube specimens measuring $15 \times 15 \times 15 \text{ cm}^3$ and cylindrical specimens with diameter and height are 15 cm and 30 cm respectively. The concrete compressive strength test was conducted at ages of 7 days, 14 days, 21 days, and 28 days, respectively. The results of the study indicated that the compressive strength of concrete produced by a mixture of 5% volcanic ash as a substitute material for cement and 5% bukho stone fractions as a substitute material for both fine and coarse aggregates was higher than that of normal concrete. A 5-10% mixture of volcanic ash and bukho stone fractions produces compressive strengths above 20 MPa for both cube and cylinder specimens. Therefore, this combination of the two materials can be considered an alternative for concrete mixes.

Keywords: Concrete, Volcanic Ash, Bukho Stone, Cube and Cylinder, Compressive Strength

1. INTRODUCTION

Infrastructure development is experiencing rapid and sustainable progress. This development requires the support of high-quality concrete materials. Concrete technology must consider the use of local materials and waste found around infrastructure projects. Local materials and waste can be used as concrete admixtures, not just to replace part of the mix.

Volcanic ash or rice husk ash can replace some of the cement in the concrete mix [1-3]. Even the use of 100% fly ash has been applied to concrete mixes [4]. Natural materials such as coal bottom ash and volcanic waste in the form of cold lava sand are used to replace some of the fine aggregate in concrete mixes [5]. Bukho stone fractions are used as a substitute material for fine and coarse aggregate [6]. A combination of several materials, such as coal fly ash as a substitute material for cement and plastic waste as a substitute material for fine aggregate, is often used for concrete mixes [7,8]. Fly ash and silica fume are combined to create a concrete mix [9]. Other combinations of materials that can increase the compressive strength of concrete include bottom ash combined with waste paper sludge ash, as well as bottom ash mixed with fly ash [9,10]. A concrete reinforcement system from a mixture of rubber fiber or carbon fiber

produces satisfactory performance on concrete compressive strength [11,12]. Reinforcement of concrete is not only reviewed based on its compressive strength, but can also be reviewed based on the flexural strength of a beam [14].

The characteristics of the local materials used must be considered to ensure they meet the specifications for concrete. The chemical composition of local materials and waste should be similar to that of materials commonly used in concrete mixes. Cement materials commonly used in concrete mixes typically contain high levels of silica. Volcanic ash often contains large quantities of this silica-like chemical property and content [15].

Aggregate properties that need to be considered include having adequate shear strength [16]. The surface shape and roughness of the aggregate can affect the compressive strength [17]. Surface shape and degree of roughness can be found in local materials such as bukho stone fractions [6].

Sustainable infrastructure development requires considering the use of locally sourced materials. Volcanic ash has a high silica content of approximately 54.56%, nearly the same as cement, so it can replace up to 10% of cement with fine aggregate from lava sand in concrete mixes [15]. The use of volcanic ash up to 8% as a substitute material for cement produces a compressive

strength value above 20 MPa and meets the quality requirements of concrete [1]. The same thing applies to the compressive strength of paving blocks, which can reach 25 MPa for fly ash mixtures [18]. The use of local materials in the form of bukho stone fractions can replace 10% of sand and more than 10% of gravel in the concrete mix [6]. Sand coated polystyrene and the recycled wastewater concrete material can be used to replace gravel in concrete mixes [19,20].

The combination of waste materials such as coal fly ash and local materials such as fine nickel slag has been proven to be able to increase the compressive strength of concrete when using 30% coal fly ash as a substitute for cement and 50% fine nickel slag as a substitute for sand [21]. The combination of 15% fly ash with 30% lime produces a concrete compressive strength that is quite high compared to other mixtures [22]. Fly ash has a chemical content in the form of silica, which is almost the same as volcanic ash, and lime has a calcium carbonate content, which is found in bukho stone fractions [6,14]. In addition to these materials, polypropylene fiber-reinforced concrete can be used to improve the performance of concrete [23].

Referring to previous research, there is an opportunity to develop a combination of concrete materials from waste in the form of volcanic ash as a substitute for cement and local materials from bukho stone fractions as a substitute for aggregate. Therefore, it is necessary to develop concrete technology from local materials in the form of bukho stone fractions as a substitute for fine and coarse aggregate and develop the use of volcanic ash as a substitute for cement, which is validated through concrete compressive strength tests on cube and cylinder test specimens. The purpose of this study is to obtain a mixture design of volcanic ash as a substitute for cement and bukho stone fractions as a substitute for aggregate in the concrete mixture, reviewed from the results of concrete compressive strength tests from cube and cylinder test specimens. The next section of this article will explain the research significance, materials and methodologies, results and discussions, conclusions, acknowledgments, and references.

2. RESEARCH SIGNIFICANCE

This research is important for the development of concrete technology from local materials, such as bukho stone fractions, as a substitute for fine and coarse aggregates. It also explores the use of volcanic ash as a substitute for cement, validated through cube and cylinder compressive strength tests for use in construction. The novelty developed in this research is the use of a combination of two materials: volcanic ash as a cement substitute and bukho stone fractions as aggregate. This

combination of the two materials has never been previously investigated, thus offering the potential for the development of paving block mixtures that can be utilized as flood-resilient road pavement layers.

3. MATERIALS AND METHODOLOGIES

3.1 Materials and Sample Preparation

The main materials of the study were volcanic ash taken from Sinabung, North Sumatra, and bukho stone taken from Nias Island North Sumatra. Waste material from the Sinabung eruption was filtered using a 200-mesh sieve, and the results are shown in Fig. 1a. Bukho stone was broken using the Los Angeles abrasion test to separate fine and coarse grains on sieve no. 4. These bukho stone fractions material is divided into two sizes, namely fine aggregate < 4.75 mm and coarse aggregate > 4.75 mm [17] (Fig. 1b). Fine aggregate uses sand material, and coarse aggregate uses gravel material taken from the Sei Wampu River, North Sumatra (Fig. 2).



Fig. 1 (a) Volcanic ash; (b) Bukho stone fractions

These materials are mixed with other commonly used concrete materials, such as cement, sand, and gravel. Volcanic ash (VA) is used to partially replace cement at 5%, 10%, 15%, and 20%, respectively. Similarly, bukho stone (BS) fractions

are used to partially replace fine and coarse aggregate compositions in the compressive strength test mix, at 0%, 5%, 10%, 15%, and 20% BS, respectively.

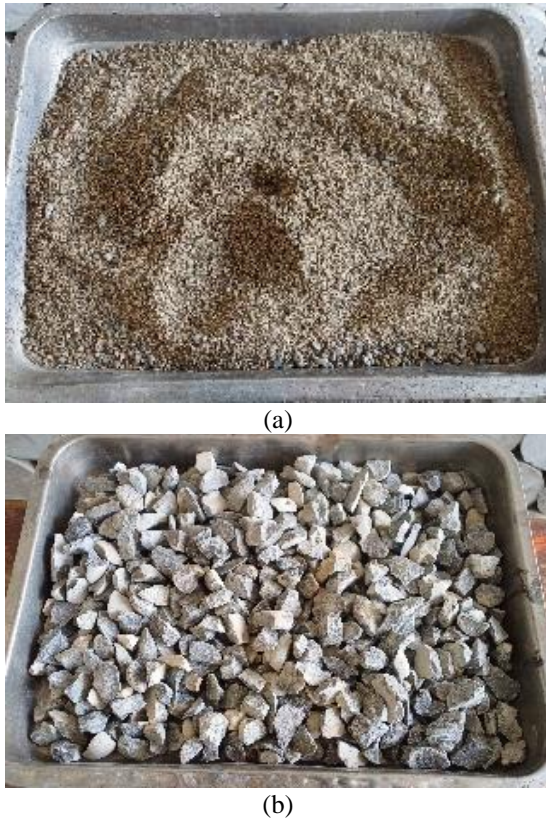


Fig. 2 Aggregate: (a) sand; (b) gravel

3.2 Testing Methodologies

Research preparation included procuring the necessary materials and preparing the tools used, including molds for cube and cylinder test specimens. These test specimens were a concrete mixture made from additional materials such as volcanic ash and bukho stone fractions. Volcanic ash was used as a partial cement substitute at 8% [1]. Meanwhile, bukho stone fractions as a substitute material for fine aggregate is used as much as 10%, and as a substitute material for coarse aggregate, it is possible to use more than 10% [6].

Each material used in the concrete mix was tested to determine the parameters required for the concrete mix design. Specifically, volcanic ash and bukho stone fractions were tested chemically to determine the chemical composition of each material. Other concrete materials were tested for density and specific gravity. Cement materials were tested for fineness and setting time.

Based on the material properties obtained, a concrete mix design was carried out to obtain the mix composition for the cube test specimen. The mix combinations used in this study were volcanic

ash (0%, 5%, 10%, 15%, and 20%) and bukho stone fractions (0%, 5%, 10%, 15%, and 20%). The concrete mix obtained was first tested with a slump test to determine the viscosity level of the mixture used. The mix design guided the mix ratio required for the test specimen. Each mixture design obtained from the previous stage was used as the basis for forming cube test specimens measuring $15 \times 15 \times 15 \text{ cm}^3$. The same mixture design was carried out on cylindrical test specimens measuring with diameter and height are 15 cm and 30 cm respectively. The test specimens for compressive strength were cubes and cylinders [24].

Each variation consisted of three test specimens. These specimens were soaked for 7, 14, 21, and 28 days before compressive strength testing. This was used to obtain the best compressive strength value from the research results [20,22]. Based on the compressive strength obtained, it provides an idea of the amount of mixture of volcanic ash and bukho stone fractions that is ideal as a concrete mixture.

4. RESULTS AND DISCUSSIONS

The results of the study are described in several important and necessary aspects to reveal the performance of concrete when mixed with a combination of local materials from volcanic ash to replace part of the cement and bukho stone fractions to replace part of the fine and coarse aggregates. The performance of concrete from the mixture of both is presented in the form of compressive strength of cube and cylinder test specimens with variations in the mixture and age of the concrete. The effect of the mixture content and age of the concrete is described to obtain the optimal mixture content for use as a concrete mixture.

4.1 Characteristics of Materials

The main characteristics of the materials used in the concrete mixture are shown in Table 1. The concrete materials used consist of sand, gravel, volcanic ash, cement, bukho stone fractions, and water. The characteristics of sand, gravel, and cement resemble those of commonly used concrete materials. Volcanic ash is made from volcanic eruption waste scattered around Mount Sinabung. This ash contains more than 72% of SiO_2 and less than 18% of Al_2O_3 . The bukho stone fraction used in this study is a volcanic rock fragment widely distributed in the Nias Islands. Physically, this rock is brownish-white with a rough texture [6]. Bukho stone fractions contain over 76% of CaCO_3 and less than 15% of Al_2O_3 . Bukho stone fractions have a density of 1.037 gr/cm^3 , and a specific gravity of 2.698. The chemical properties of bukho stone grains are close to those of lime material. Lime has a main content of CaCO_3 is 84.85%, SiO_2 of 7.06%,

and Al_2O_3 of 2.38% [25]. The chemical composition of volcanic ash and bukho stone materials consists of SiO_2 and CaO these properties are also in the composition of cement [26].

Table 1. Characteristics of materials

Sand	Sand from the Sei Wampu River, with a density of 1.631 gr/cm ³ , and a specific gravity of 2.508
Gravel	Gravel from the Sei Wampu River, with a density of 1.462 gr/cm ³ , and a specific gravity of 2.704
Volcanic ash	Volcanic ash from Sinabung contains more than 72% of SiO_2 and less than 18% of Al_2O_3
Cement	Portland Cement Type I, density 1.053 of gr/cm ³
Bukho stone fraction	Natural stone is a natural stone from Nias, with a density of 1.037 gr/cm ³ , and a specific gravity of 2.698, more than 76% of $CaCO_3$ containing over 15% of Al_2O_3
Water	Clean and free from impurities

4.2 The Results of the Concrete Compressive Strength Test

The results of the concrete compressive strength test from a mixture of volcanic ash and bukho stone fractions are seen from the concrete cube and cylinder test specimens. The results of the concrete compressive strength test from the cube test specimen are shown in Fig. 3. While the results of the concrete compressive strength test from the cylinder test specimen are shown in Fig. 4.

The compressive strength test results are the maximum load divided by the area of the test object.

Each test object variation consists of two samples each for concrete ages 7 days, 14 days, 21 days, and 28 days. Overall, it was found that the concrete compressive strength values of the two samples were not much different from each other.

The compressive strength of cubic and cylindrical specimens increased when using 5% volcanic ash and 5% bukho stone fractions. The use of volcanic ash and bukho stone fractions above 5% shows a decrease in the compressive strength of concrete along with the addition of both. All test specimens showed an increase in concrete compressive strength with age, both for cube specimens and cylindrical specimens. Concrete aged 14 days and above shows a significant increase in cube specimens, but cylindrical specimens show an almost uniform increase at each concrete age.

4.3 Effect of Concrete Age on Compressive Strength

Two test specimens, both cube and cylinder, describe the effect of concrete age on the compressive strength. Both are shown in Fig. 5 and Fig. 6. The concrete age of 14 days has a significant effect on the cube test specimen; this is seen from the quite high increase from the concrete age of 7 days to 14 days, while the increase in compressive strength from 14 days to 21 days is almost the same as the increase in compressive strength of concrete from 21 days to 28 days. This uniform size in all directions of the cube test specimen allows for a more even concrete hardening process throughout.

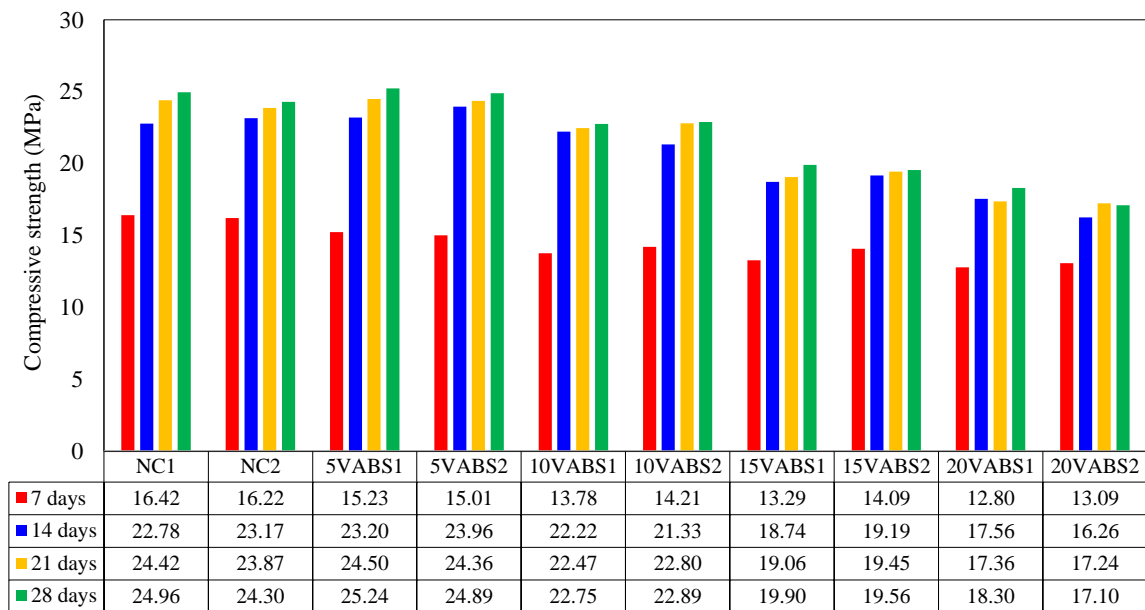


Fig. 3 The result test on the cube with volcanic ash and bukho stone fractions

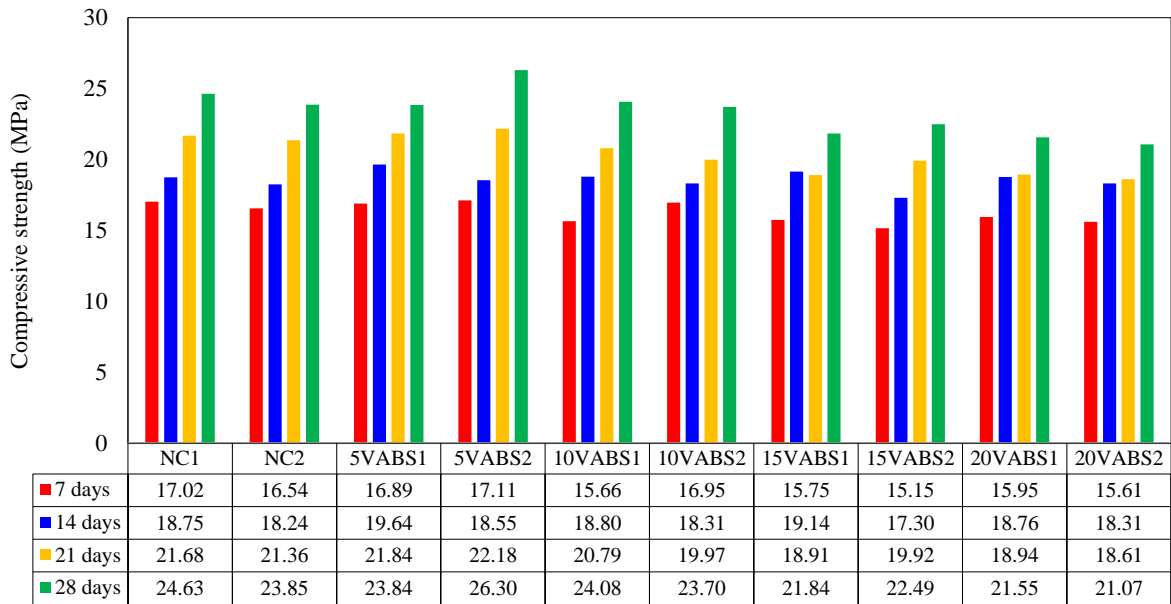


Fig. 4 The result test on the cylinder with volcanic ash and bukho stone fractions

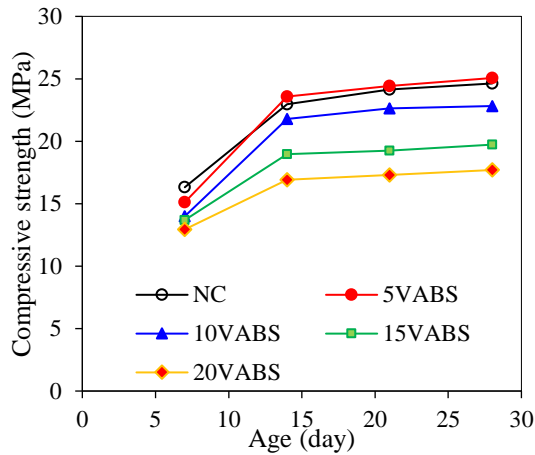


Fig. 5 Effect of concrete age on cube specimens

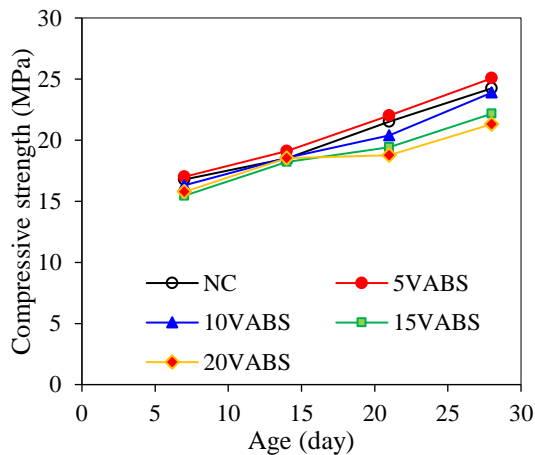


Fig. 6 Effect of concrete age on cylinder specimens

The compressive strength of concrete with a mixture of 5% volcanic ash and 5% bukho stone fractions (5VABS) was significantly higher than that of normal concrete (NC) at 14-28 days. However, the compressive strength of mixtures containing 10-20% VABS was lower than that of NC.

The concrete compressive strength of cylindrical test specimens aged 7-14 days appears to be almost the same for all specimens. This means that volcanic ash and bukho stone fractions have not shown a significant effect on the concrete compressive strength aged 7-14 days. This is different from the concrete aged 21 days and 28 days. The compressive strength of each specimen shows differences from the other. The compressive strength with a mixture of 5% volcanic ash and 5% bukho stone fractions is higher than that of NC, while a mixture of 10-20% VABS produces a lower compressive strength than NC.

Concrete aged 28 days showed the highest compressive strength compared to the others. Concrete age significantly influences the compressive strength of both normal concrete (NC) and concrete with a mixture of both materials (VABS). This is due to the pozzolanic reaction that continues to occur in the concrete specimens as the concrete ages [27].

4.4 Effect of Volcanic Ash and Bukho Stone Content on Compressive Strength

The effect of volcanic ash and bukho stone fractions in the concrete mixture is shown in Fig. 7

for cube specimens and Fig. 8 for cylinder specimens. The compressive strength of the cube specimens for the mixture of volcanic ash and bukho stone fractions generally decreases for additions above 5%, but the compressive strength for the 5% VABS mixture increases compared to the NC compressive strength, especially at the age of 14-28 days. This means that the use of this material has a positive impact on increasing the compressive strength of the 5% VABS mixture. The compressive strength of the cube specimens with a mixture of 5-10% VABS is still above 20 MPa, while 15-20% VABS shows a compressive strength below 20 MPa. The compressive strength of the cube specimens appears stable at 14-28 days, while at the age of 7 days the compressive strength is still low. Overall, it was found that the compressive strength for the mixture was up to 5-20% VABS higher than 17.2 MPa and met the minimum compressive strength requirements for structural concrete according to the International Building Code and the ACI 318 standard [28].

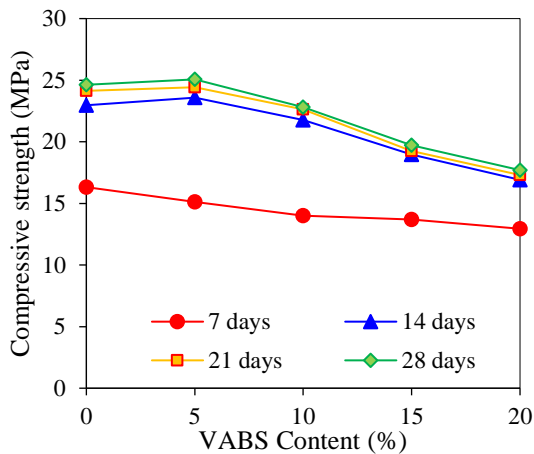


Fig. 7 Effect of VABS content on cube specimens

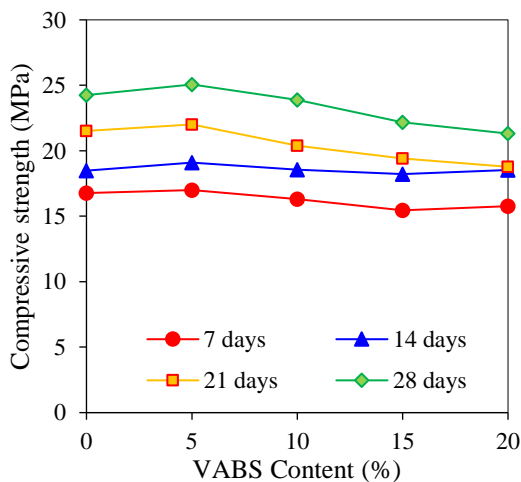


Fig. 8 Effect of VABS content on cylinder specimens

The compressive strength of the cylindrical specimens showed a similar pattern to that of the cube specimens. An increase in concrete compressive strength was obtained with a mixture of 5% VABS. However, mixtures above 5% VABS were still seen as smaller compared to the NC compressive strength. The compressive strength of the cylindrical specimens for 28 days was all found to be higher than 20 MPa, slightly different from the concrete strength of the cube specimens. The effect of concrete age on the cylindrical specimens was also seen to be uniform for each additional age of the concrete from 7 days to 28 days. This can be interpreted as meaning that the concrete is still hardening up to the age of 28 days.

4.5 Comparison of Compressive Strength to Compressive Strength at 28 Days

The comparison of concrete compressive strength at each age to compressive strength at 28 days for both cube and cylinder test specimens is shown in Fig. 9 and Fig. 10.

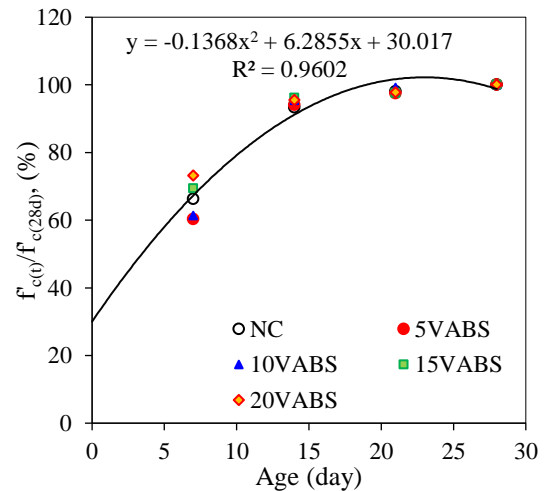


Fig. 9 Comparison of compressive strength to compressive strength at 28 days on cube specimens

The comparison of the compressive strength of the cube test specimens for each concrete age to the concrete age of 28 days was obtained: 69% at the age of 7 days, 96% at the age of 14 days, and 98% at the age of 21 days. This shows that 14-day-old concrete is almost the same as 28-day-old concrete. This is slightly different from the cylindrical test specimens. The comparison of the compressive strength of the concrete to the concrete age of 28 days was obtained at 70% at the age of 7 days, 80% at the age of 14 days, and 88% at the age of 21 days. The cube test specimens experienced a faster hardening process than the cylindrical test specimens. The cube test specimens curved

downward, while the cylindrical test specimens experienced an almost linear increase for each stage of the concrete age. Concrete compressive strength can be increased by using circular steel tubes [29].

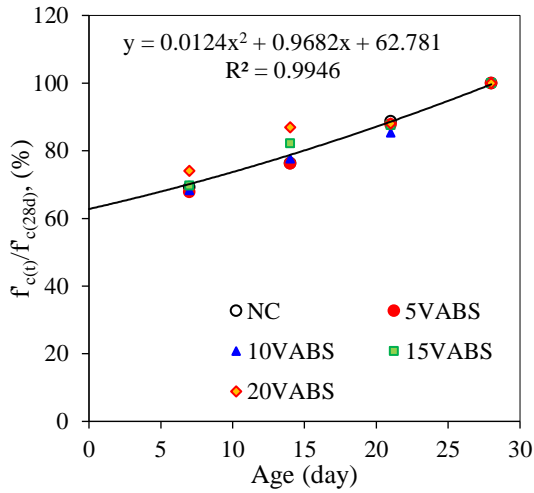


Fig. 10 Comparison of compressive strength to compressive strength at 28 days on cylinder specimens

The comparison of concrete compressive strength for each mixture to the normal concrete compressive strength at 28 days of age of both test specimens is shown in Fig. 11. Both forms of test specimens show an increase in concrete compressive strength in the 5% VABS mixture; the compressive strength of both test specimens in this mixture is found to be higher than the NC compressive strength.

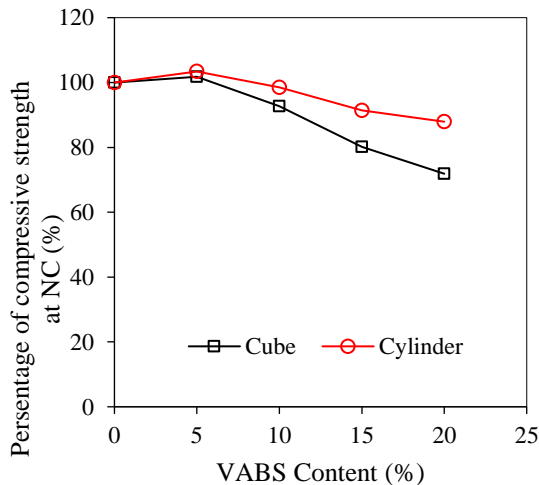


Fig. 11 Comparison of compressive strength to compressive strength NC

The use of 2-4% volcanic ash as a cement substitute produces compressive strength above normal concrete according to previous research [1]. The

compressive strength for the 10% VABS mixture is found to be still close to the same as the NC compressive strength or more than 90% of the NC compressive strength. Thus, it can be said that the concrete mixture of volcanic ash and bukho stone fractions can achieve the equivalent of normal concrete compressive strength when using 5-10% VA as a substitute material for for cement and 5-10% BS as as a substitute material for fine aggregate and coarse aggregate.

5. CONCLUSIONS

The conclusions of this study are:

1. A mixture containing 5% volcanic ash as a substitute material for cement and 5% bukho stone fractions as a substitute material for fine and coarse aggregate achieves the highest compressive strength for both cube and cylinder test specimens.
2. A mixture containing 5-10% of the two materials used demonstrates performance similar to that of normal concrete; therefore, this amount can be considered for use in concrete mixtures. While a mixture above 10% produces a relatively low settlement, it is not recommended to obtain good compressive strength.
3. The compressive strength at the age of 14 days for the cube test specimen produces a stable compressive strength and is almost the same as the compressive strength at the age of 28 days; this indicates that the concrete mixture for the cube test specimen hardens faster than the cylinder test specimen.
4. Overall, the compressive strength of the cube specimens at 28 days was found to be 20 MPa higher when mixed with 5-10% volcanic ash and bukho stone fractions. Meanwhile, the compressive strength of the cylindrical specimens at 28 days was above 20 MPa.

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