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Original Article

Compressive and Splitting Tensile Strength of Concrete Using Granite Waste as Coarse Aggregate

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Abstract *- The increasing use of concrete for construction activities means an increasing need for concrete, thus triggering large-scale mining of rock and sand as concrete-forming materials. This can result in natural damage and reduced availability of natural resources. On the other hand, there is Granite Waste (GW) left over from processing granite as a building material. So far, GW production has not been managed properly. Generally, GW is left to pile up in limited work areas or is simply thrown away as fill material, so it has little economic value and pollutes the environment. This research aims to examine the effectiveness of GW in granular form as a coarse aggregate in making concrete. The effectiveness of the use of this waste is measured by comparing the compressive strength and the splitting tensile strength of concrete prepared by using GW coarse aggregate with that made by using natural Crushed Stone (CS) coarse aggregate or its mixture. The strength measurements are carried out after 28 days of hydration using 150x150x150 mm cubes for compressive strength and cylinders measuring 150 mm in diameter and 300 mm high for splitting tensile strength. The results of measurements and discussions show that the compressive and the tensile strength of concrete augment proportionally up to the use of 70% GW coarse aggregate and then tend to decrease. Furthermore, they also show that the ratio of the compressive strength/the splitting tensile strength increased proportionally with increasing use of GW coarse aggregate in the mixture.*

Keywords *- Compressive strength, Granite waste, Splitting tensile strength.*

1. Introduction

Concrete is the most frequently used building material in the construction services industry. The performance of concrete is mainly determined by its constituent materials, namely water, cement and aggregate. Therefore, attention must be paid to this material so that concrete of the quality according to plan is produced. It is known that in making concrete, the use of aggregate in the form of fine aggregate and coarse aggregate ranges from 65% to 75% of the total weight of materials required. This means that a good understanding of the characteristics of the aggregate to be used in making concrete cannot be ignored. As we know, certain buildings in Bali use a lot of natural stone such as brick, marble and granite, which gives a beautiful and natural impression. Granite, which is a type of igneous rock, is widely used because it has attractive patterns and colors, is strong and hard, and is easy to care for and clean. However, the use of granite leaves pieces of stone in the form of construction waste. In Bali, one of the areas producing Granite Waste (GW) is in the Canggu area, Badung Regency. This is related to the many tourism-supporting buildings there that use granite as finishing materials for floors, walls and ornaments. This use results in a lot of waste from granite stone fragments, which has an impact on environmental pollution because waste is usually left to accumulate around work areas, causing environmental disturbances. To reduce this problem, it is necessary to develop a way to process GW. One approach that can be studied is using GW as a substitute for coarse aggregate in making concrete. This is because the form of GW is in the form of rock fragments which have a hard surface, so it is worth considering as a partial or complete replacement for natural coarse aggregate in making concrete. To determine whether GW can be used as a substitute for coarse aggregate in making concrete, it is necessary to study the quality of the concrete produced. Several studies concerning the use of granite as aggregate in concrete production have been conducted previously. According to Aginam et al. [1], the use of crushed granite as coarse aggregate in concrete produced best in compression strength than those made with washed gravel and unwashed gravel of similar grading. A comparative analysis of concrete made with quarry-crushed and locally sourced coarse aggregate has been realized by Nduka [2]. Based on this study, it is proposed to use granite rather than gravel for higher-strength concrete applications. Tufail et al. [3] studied the effect of elevated temperature on the mechanical properties of limestone, quartzite and granite concrete. It is found that the mechanical properties of concrete were strongly influenced by increasing temperature and the mineralogy of coarse aggregate used. The mechanical strength and modulus of elasticity of concrete decreased with increasing temperature, while the ultimate strain in compression augmented. Interestingly, it was also found that concrete made from coarse granite aggregate showed higher mechanical properties at all temperatures, followed by quartzite and limestone concretes. A study on the replacement of coarse aggregate by granite chips in concrete has been realized by Sharma et al. [4] through studying the strength produced by the concrete made. It is concluded that the strength of the concrete produced is comparable with that of conventional concrete. Sharma et al. [5] evaluated the properties of concrete using polished granite waste as a partial substitution for coarse aggregate. It is found that the use of polished granite waste in concrete decreases the mechanical properties but better results are observed for physical properties. Previous studies have shown that granite is potentially to be used as concrete aggregate. However, it needs to be studied in more depth regarding the strength performance of concrete made from GW aggregate, especially when mixed with natural stone aggregate. In this research, the opportunity to utilize GW in granular form as coarse aggregate for making concrete will be studied. The effectiveness of using GW will be measured from the mechanical strength of the concrete including compressive and splitting tensile strength produced at 28 days.

2. Materials and Methods

This study was realized using concrete-forming material. The water used was tap water while for hydraulic binder, it was used the type of Portland Pozzolan Cement (PPC) conforming to SNI 15-0302-2004 [6]. The fine aggregate (FA) used was natural sand (NS). As for coarse aggregate (CA), it was used two types of CA: crushed (CS) stone and GW. The NS and CS were purchased from building materials suppliers, while GW was taken from around the construction work area. Before being used as CA, GW is crushed with a hammer to obtain granules with a diameter of 4.0 - 40.0 mm according to the CA category. The gradation curve for FA and CA granules was then designed referring to SNI 03-2834-2000 [7], fulfilling zone 2 for FA and granules with a maximum diameter of 40 mm for CA. Some physical properties of FA and CA are given in Table 1, while their gradation curves are presented in Figures 1 and 2.

Four concrete mixture compositions were studied. The ingredients composition for each concrete mixture was determined in a weight ratio, PPC: FA: CA of 1:2:3. A water/hydraulic binder ratio of 0.5 was used for all compositions. The use of GW as CA in concrete mixture varied from 0% to 100%, as presented in Table 2. The mixture M1 was used as a control.

A laboratory mixer was used to stir concrete mixtures. Before stirring, the FA and CA aggregates were prepared in Saturated Surface Dry (SSD) condition. After stirring, cubical specimens sizing 150 x 150 x 150 mm and cylinder specimens measuring 150 mm in diameter and 300 mm high were cast, referring to SNI 2493-2011 [8]. After that, all of the specimens were kept in molds for 1 day and then were demolded and cured directly in water until used for strength tests. Five specimens were made for respectively compressive and splitting tensile strength tests for each mixture proportion. The strength tests were carried out after the specimens were 28 days old. The compressive strength test was carried out according to SNI 03-1974-1990 [9], while the splitting tensile strength test was conducted referring to SNI 2491-2014 [10]. Figure 3 shows the activity of concrete stirring, specimens casting and curing as well as strength testing.

Table 1. Physical properties of FA and CA

Physical Properties	FA	CA	
	NS	CS	GW
Unit weight (g/cm^3)	1.33	1.34	1.89
Specific weight SSD	2.47	2.56	2.75
Absorption (%)	4.68	2.25	0.35
Abrasion (%)	-	28.79	11.69

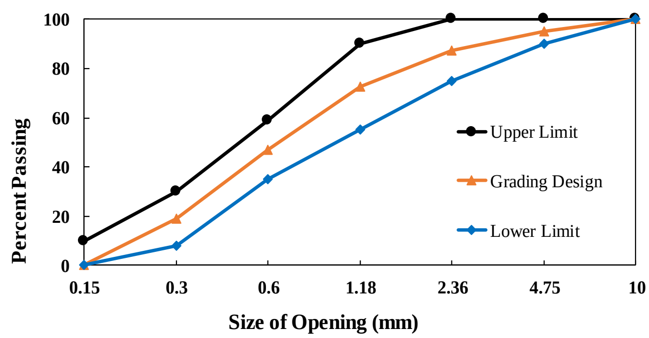

Fig. 1 Design gradation curve for FA

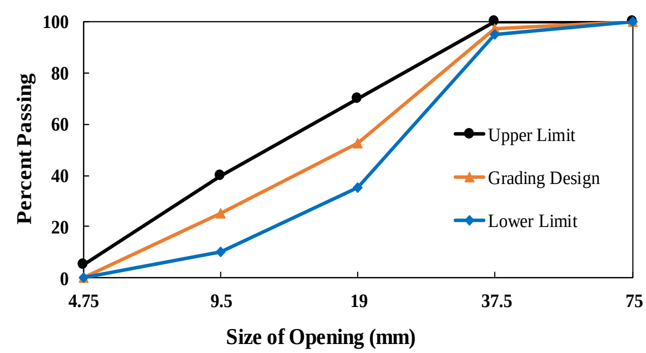

Fig. 2 Design gradation curve for CA

Table 2. Proportion of GW and CS in concrete mixture

Mixture	CA Composition	
	GW (%)	CS (%)
M1	0	100
M2	30	70
M3	50	50
M4	100	0

Fig. 3 Mixing, casting, curing and testing

3. Results and Discussion

3.1. Results

The test results of compressive and splitting tensile strength for each composition are presented in Table 3. Figure 4 illustrates changes in those strengths according to the quantity of GW used in the concrete mixture. Table 3 and Figure 4 clearly show that the strength of concrete, compressive as well as splitting tensile strength, is augmented by increasing the GW/(GW+CS) ratio in the concrete mixture. Those strengths increase up to the use of a GW/(GW+CS) ratio of 70% and tend to decrease thereafter. For concrete mixture with GW/(GW+CS) ratio increasing from 0% to 70%, the compressive strength increases from 17.6 MPa to 35.8 MPa while the splitting tensile strength increases from 2.2 MPa to 3.0 MPa.

Table 3. Compressive and splitting tensile strength of concrete mixture

Mixture	Compressive Strength (MPa)	Splitting Tensile Strength (MPa)
M1	17.6	2.2
M2	24.6	2.6
M3	35.8	3.0
M4	29.8	1.9

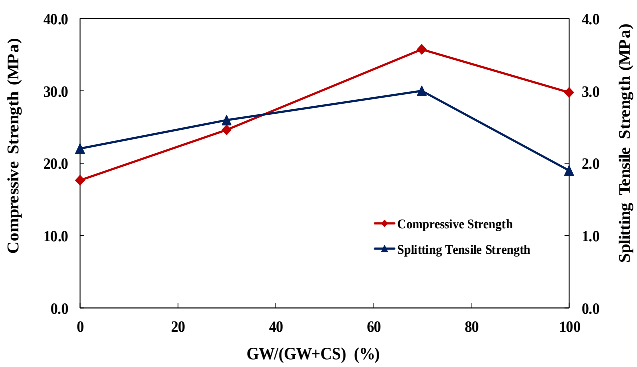

Fig. 4 Compressive and splitting tensile strength with variations in GW content in concrete mixture

However, the use of a GW/(GW+CS) ratio from 70% to 100% resulted in the compressive strength being reduced from 35.8 MPa to 29.8 MPa and the splitting tensile strength being reduced from 3.0 MPa to 1.9 MPa. These results have a similar trend to the results of the previous study [5].

3.2 Discussion

Changing the type of coarse aggregate used in the concrete mixture results in changes in concrete properties both in the plastic condition and after the concrete has hardened [11-13]. In this research, the properties of concrete after hardening are indicated by its compressive and splitting tensile strength. Indeed, the strength test results of concrete with variations in the GW/(GW+CS) ratio clearly show the effect of using GW as CA on the mechanical properties of the resulting concrete. This effect was observed both using GW as total CA and a mixture of GW with CS.

In terms of strength, the use of GW as CA, total or mixed with CS, generally gives better results compared to using CS alone. In fact, the test results show that the compressive and splitting tensile strength of concrete tends to increase with the use of up to 70% of GW as coarse aggregate and then tends to decrease. Using 100% of GW as coarse aggregate produces lower compressive strength than using 70% but still produces higher compressive strength than using 30% or 0%. The same phenomenon was also observed in the splitting tensile strength test results, only when using 100% of GW as coarse aggregate the splitting tensile strength was lower than using other proportions of GW.

In general, it can be said that the use of GW as coarse aggregate provides benefits from a strength point of view, especially for compressive strength. Also, it is noted that the combination of using GW and CS as coarse aggregates produces better strength when compared to using each coarse aggregate individually. It seems that the combination of these two types of coarse aggregate produces a better bond compared to using each type of aggregate individually. This results in the strength produced by concrete with mixed coarse aggregates being better.

This was confirmed through further test data analysis which showed that the use of GW as CA in concrete mixture was able to produce a higher compressive strength/splitting tensile strength ratio if more GW coarse aggregate was used, as presented in Figure 5. This is proven by the results of the regression analysis, which gives the mathematical equation $y = 0.075x + 7.531$, with a determination coefficient value of $r^2 = 0.96$ and a correlation coefficient value of $r = 0.98$. In this case, y is the ratio of the compressive strength/ splitting tensile strength, while x is the proportion of GW to the total coarse aggregate (GW + CS). The correlation coefficient value of r shows that there is a positive and significant relationship between the proportion of coarse aggregate GW and the compressive strength/splitting tensile strength ratio.

Paying attention to the coefficient of determination value, it can be seen that 96% of the compressive strength/splitting tensile strength ratio value of concrete with coarse aggregate mixed with GW and CS is determined by the proportion of GW and the remainder is determined by other factors.

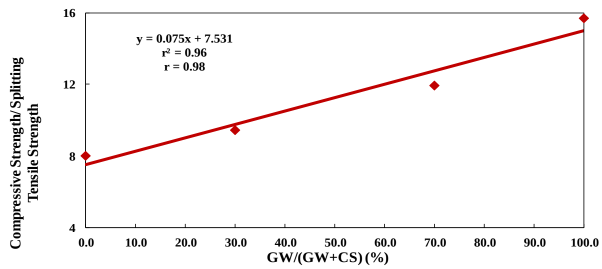

Fig. 5 Compressive strength/splitting tensile strength ratio with variations in GW content in the concrete mixture

4. Conclusion

Based on the results obtained from this research and the discussions realized, the following can be concluded.

- The use of GW as CA provides benefits from a strength point of view, especially for compressive strength.
- The combination of using GW and CS as CA produces better strength when compared to using each CA individually.
- The use of GW as CA in concrete mix produces a higher compressive strength/splitting tensile strength ratio if more GW was used as CA.
- The relationship between y, which is the ratio of the compressive strength/splitting tensile strength and x, which is the ratio of GW to the total of CA (GW + CS), is y = 0.075 x + 7.531, with a determination coefficient value of r^2 = 0.96 and a correlation coefficient value of r = 0.98.

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