Journal of the Civil Engineering Forum, May 2024, 10(2):209-216
DOI 10.22146/jcef.11305
Available Online at https://jurnal.ugm.ac.id/v3/jcef/issue/archive

Effect of the Specimen's Height on the Split-Tensile Strength of the Fibers Reinforced Clay- Lime - Rice Husk Ask Mixture

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SUBMITTED 11 January 2024 **REVISED** 12 February 2024 **ACCEPTED** 22 March 2024

ABSTRACT Various studies on the effect of specimen size on splitting tensile strength. However, geotechnical codes lack consensus regarding the recommended specimen diameter and height-to-diameter (*H/D*) ratio for the split tensile strength test. Hence, it is imperative to study the effect of the height-to-diameter ratio of the specimen on the outcomes of the split tensile strength test, especially for stabilized and fiber-reinforced soil. This research examines the effect of adding lime-rice husk ash and plastic fiber and the effect of specimen size on splitting tensile strength. The height of the specimen is varied, using a height-to-diameter ratio (*H/D*), namely 0.5, 1.0, 1.5, 2.0, and 2.5, in which the diameter is 70 mm. Two groups of specimens were prepared as stabilized clay without fibers and stabilized clay with 0.1% fibers. The lime required for stabilization is 10% of the dry weight of the soil. In this research, the lime and rice husk ash ratio was designed as 1:1. The splitting tensile strength test was carried out after the specimen was cured for seven days. The investigation indicates that the splitting tensile strength of the specimen without fibers reduces from 217 kPa to 150 kPa as the *H/D* ratio grows from 0.5 to 2.5. Conversely, the tensile strength of the specimen with fibers increases from 284 kPa to 357 kPa. The findings suggest that the fiber inclusion enhances the splitting tensile strength of the stabilized clay. The specimen size affects the splitting tensile strength, but the effect becomes less noticeable when the *H/D* ratio exceeds 2.5. From a fracture mechanism perspective, the specimen experiences mode II (shearing) due to a probable "flexural action" along its height. It remains challenging to conclude the dimensions of the test specimen or, at the very least, estimate the correction factor for the size-to-tensile strength ratio.

KEYWORDS Soil Stabilization, Lime, Rice Husk Ash, Fiber, Split Tensile Strength, Specimen Size

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1 INTRODUCTION

Soil stabilization is usually carried out in dam base soil, embankment, highways, roadways, railways, and runways construction. Soil stabilization by adding chemicals, such as cement, lime, or other cemented materials (e.g., fly ash, rice husk ash), increases strength and reduces compressibility (Altun et al., 2009). A study conducted by Muntohar (2009) on the effect of plastic fibers on the strength of clay stabilized by lime-rice husk ash showed that the optimum compressive and tensile strength was attained at fiber content ranging from 0.4% to 0.6%. Furthermore, the effective plastic fiber length was in the range of 20 mm to 40 mm to achieve the highest compressive and tensile strength. Even though efforts have been made to study the behavior of the fibers-reinforced soil, some factors influence the tensile strength value of soil. Consoli et al. (2010) stated that the main influencing parameters for soil mixed with cement are the amount of cement content, porosity, the ratio of voids and cement content, and the age of the specimen. In general, Krishnayya and Eisenstein (1974) mentioned a number of parameters, such as water content, degree of density, loading rate, test duration, and suction, especially for cohesive soils (Harison et al., 1994).

Another factor that influences tensile strength is the specimen size effect. Various studies on the effect of specimen size on splitting tensile strength show that the magnitude of splitting tensile strength depends on the diameter (Bazant et al., 1991). Previous experiments by Sabnis and Mirza (1979), Chen and Yuan (1980), Ross et al. (1989) concluded that splitting tensile strength decreases with decreasing diameter size. However, the opposite results were concluded by Hasegawa et al. (1985). Specimen size is a fundamental issue related to fiber-reinforced soil since the length of fibers is limited by the specimen diameter and length. Muntohar (2011) studied the split tensile strength of the fiber-reinforced soil–lime–rice husk ash mixtures, which increased with an increase in the specimen diameter. The experiment recommended that the specimen diameter for the split tensile test should be 70 mm; increasing the specimen diameter to greater than 70 mm did not significantly change the tensile strength.

Table 1. The index properties of the soil sample

Properties	Value
Specific gravity, G_s	2.55
Moisture	6%
Liquid limit	73%
Plastic limit	33%
Plasticity index	40%
Fines fraction (clay/silt)	93%
Coarse fraction (sand)	7%
Maximum dry density, γ_{dmax}	12.1 kN m^{-3}
Optimum moisture content, w_{opt}	38%

Determination of the splitting tensile strength of stabilized soil is also required in the pavement design (Muntohar et al., 2021). The tensile strength testing method using the splitting tensile strength test does not yet have a standard size for the specimen. Previous studies that examined the tensile strength of soil still used various standards, such as ASTM C496 for concrete and AASHTO T245 for asphalt. Therefore, there is disagreement across standard codes about the different specimen diameter and height-to-diameter (*H/D*) ratio recommendations made by geotechnical codes. For this reason, it is necessary to study the influence of the height-to-diameter ratio of the specimen on the split tensile strength test results of clay soil reinforced with lime and plastic sack fiber. This research continues the preliminary finding from Muntohar (2011) by extending the number of *H/D* ratios.

2 METHODS

2.1 Experimental Design

Overall, the primary test of this research was the split tensile strength test, but initial tests were carried out, including water content, specific gravity, liquid limit, plastic limit, sieve analysis, and standard Proctor compaction tests to determine the characteristics of the soil to be used. Specimens were prepared by sieving the soil passed the No. 4 sieve, lime, and plastic sack fiber according to predetermined proportions. The tests were carried out after the specimen was cured for seven days. The height-to-diameter ratio (*H/D*) was varied from 0.5 to 2.5, with the *D* (diameter) set at 70 mm. The initial consumption of lime (*ICL*) test was carried out to determine the lime content for stabilization. The *ICL* test determined that the lime required for stabilization was 10% by the dry weight of the soil. In this research, the lime and rice husk ash ratio was designed as 1:1. The fiber content was defined as 0.1% by the dry weight of soil, and the fiber length was 40 mm.

Table 2. Chemical composition of the lime and rice husk ash

Constituent	Rice Husk Ash	Hydrated Lime
Al_2O_3	1.17	0.15
CaO	0.48	68.25
Fe_2O_3	0.98	0.10
MgO	0.13	0.22
Na_2O	0.22	0.12
K_2O	1.54	0.02
SiO_2	87.68	0.06
SO_3	0.39	1.12

2.2 Soil, Lime, Rice Husk Ash, and Fibers

The soil originated from Bangunjiwo, Bantul, Special Region of Yogyakarta. Index properties were conducted, and the results are shown in Table 1. The soil sample mainly consisted of 93% clay/silt fraction, and the remaining was sand fraction. Based on the soil fraction and consistency limits (liquid limit and plastic limit), the soil can be classified into heavy clay or high plasticity clay with a CH symbol according to the Unified Soil Classification System.

The lime used in this research was hydrated lime ($Ca(OH)_2$). The primary chemical composition of lime is calcium oxide (CaO), as presented in Table 2. The rice husk ash (RHA) was obtained from open burnt husks in Piyungan, Bantul, Special Region of Yogyakarta. The only grey-color ashes were collected and stored in gunny sacks. The RHAs were grounded using a modified Los Angeles machine to obtain fine-grain RHAs. The RHA consisted of 87% silica oxide, as presented in Table 2.

Polypropylene (PP) fibers were used from plastics gunny (see Figure 1a). The fibers of the plastic gunny were cut into small pieces ±40 mm long, with a single fiber width of ±2.5 mm (Figure 1b). Physically, the plastic gunny fibers were not brittle or ruined when pulled by hand. Thus, the fibers remain capable of providing tensile resistance. The tensile strength of the fibers was 63 kN m^{-1} per width.

2.3 Specimen preparation

The specimen mold was a cylindrical shape made of steel plate. This mold was designed as a splitting mold to make it easier to remove the specimen after compacting. All specimens were compacted at the γ_{dmax} and w_{opt} of the soil (see Table 1). Soils, lime, and RHA were prepared in oven dry and put in the mixer machine. The blade rotated for about 10 minutes until homogenously mixed. The fibers were then carefully added into the bowl and stirred slowly for 5-10 minutes. Water was added gradually into the bowl while the blade rotated

Figure 1 (a) Used plastic gunny, (b) the fibers

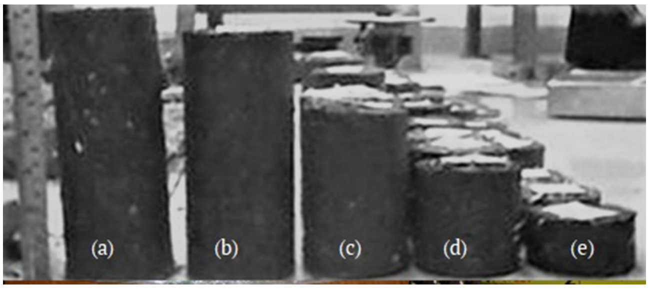


Figure 2 Specimen after dismantled from molds with various height to diameter (*H/D*) ratios: (a) *H/D* = 2.5, (b) *H/D* = 2, (c) *H/D* = 1.5, (d) *H/D* = 1, and (e) *H/D* = 0.5.

until a homogeneous slurry. The amount of water was defined as the optimum moisture content. The mixing was terminated, and the slurry was put into the cylinder mold as targeted unit weight and compacted statically. The compacted specimen was dismantled from the mold, and the weight and size (diameter and height) were measured. The specimen was stored in a sealed plastic bag for seven days of curing. Figure 2 shows the specimens after curing. Three set specimens were prepared for each *H/D* ratio.

2.4 Split-tensile strength test

The split tensile strength test was carried out on a universal compression testing machine. Before testing, the specimen was sized, weighed, and then installed on the baseplate of the compression machine. The specimen was arranged at the centerline of the loading plate. Two horizontal dial gauges were adjusted at the left and right sides of the specimen (see Figure 3). The dial gauges measured diametrical deformation. After the specimen was set up, the machine was turned on, and vertical loading and deformation were recorded every 30 seconds. The test ceased when the specimens failed or the load immediately decreased after reaching the peak load. The peak load was determined as the maximum load (P_{max}). The split tensile strength is calculated using Equation (1).

$$T_u = \frac{2P_{max}}{\pi HD} \tag{1}$$

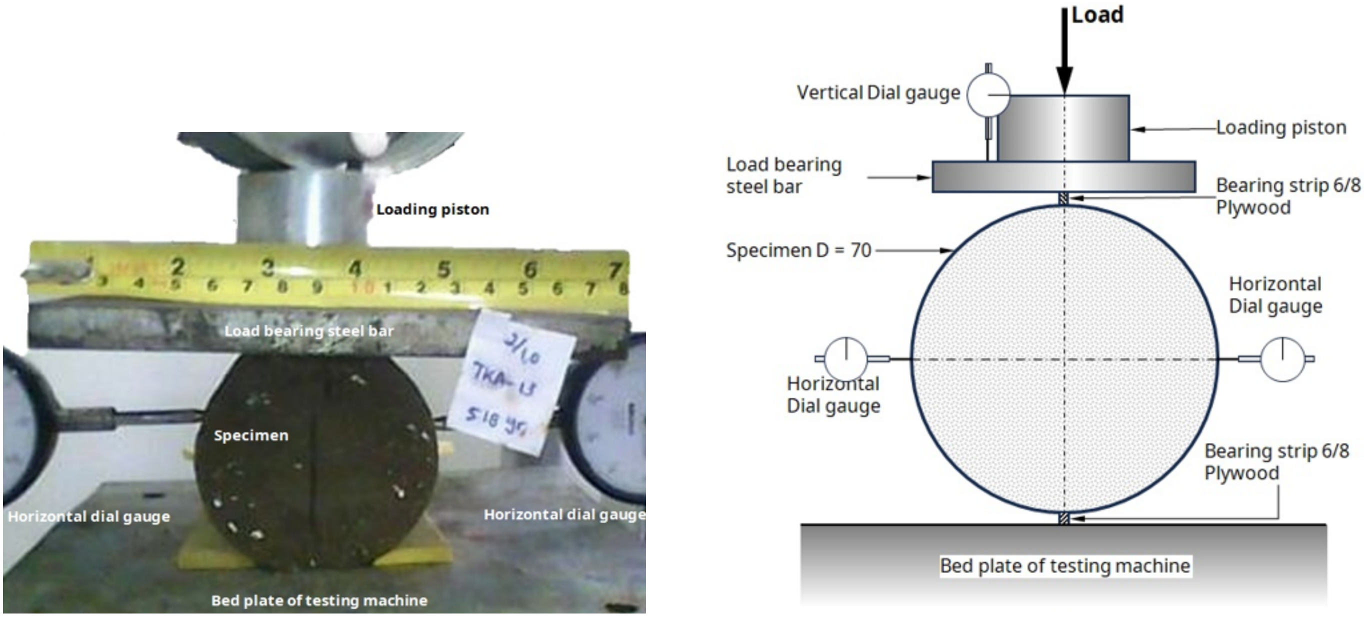
where T_u = ultimate tensile strength (kPa), P_{max} = maximum load at failure (N), H = Average height of specimen (mm), D = average diameter of specimen (mm).

3 RESULTS AND DISCUSSION

3.1 Result

This work examined various soil *H/D* ratios, and the ratios were limited from 0.5 to 2.5. The mean split tensile strength values (T_{avg}) for corresponding *H/D* ratios are listed in Table 3 and visually represented in Figure 3. The standard deviation (s_d) and coefficient of variation (*cov*) among the tested specimens with various *H/D* ratios are also summarized in Table 3. The coefficient of variation is a statistical indicator of the relative dispersion of data points in a data series around the mean. In a small sample size, Bayesian theory can be applied to the coefficient of variation to determine the characteristic value of geotechnical properties (Prästings et al., 2019). The split tensile strength of the specimen without fibers decreases from 217 kPa to 150 kPa by increasing the *H/D* from 0.5 to 2.5, while the tensile strength of the specimen with fibers increases from 284 kPa to 357 kPa. The results indicate that fibers can improve the split tensile strength of the stabilized clay.

Figure 4 plots the relationship between the specimen size ratio and the split tensile strength of the unreinforced and fiber-reinforced clay. The mean split tensile strength and standard deviation are represented by



(a) (b)

Figure 3 (a) Arrangement of the test, (b) Schematic diagram of the split tensile test

Table 3. Summary of the average tensile strength of the stabilized clay with various *H/D* ratio

H/D	Without fibers			With 0.1% Fibers		
	T_{avg} (kPa)	s_d (kPa)	*cov*	T_{avg} (kPa)	s_d (kPa)	*cov*
0.5	217	18.4	0.085	284	6.4	0.023
1.0	189	9.8	0.052	327	8.1	0.025
1.5	183	19.9	0.109	337	20.9	0.062
2.0	168	10.0	0.059	353	15.3	0.043
2.5	150	18.7	0.125	357	16.1	0.045

s_d = standard deviation of three specimen tested, *cov* = coefficient of variation = s_d/T_{avg}

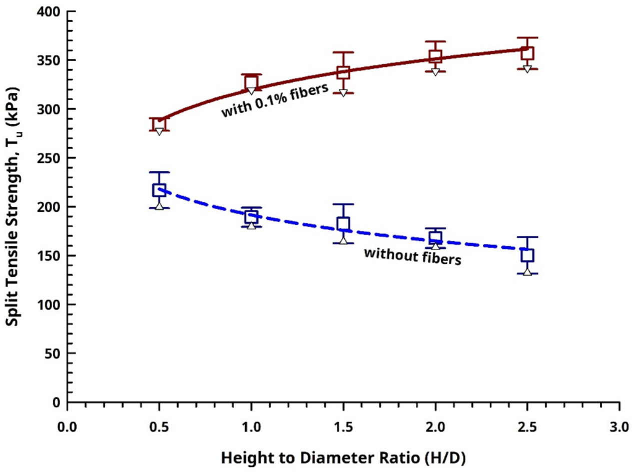


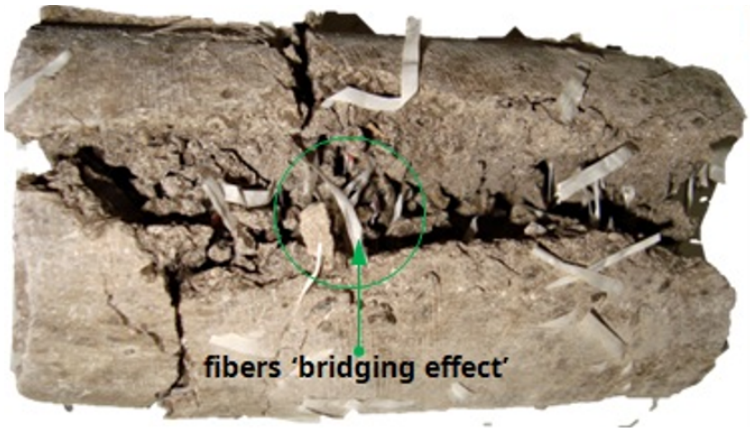
Figure 4 Effect of the height-to-diameter ratio (*H/D*) of the test specimen on the tensile strength of the stabilized and reinforced clay.

the open symbols and error, respectively. The trendlines in Figure 4 show that the split tensile strength decreases with increasing *H/D* for stabilized clay without fibers. In contrast, for the stabilized soil with fibers, the split tensile strength increases with the *H/D* ratio. The trendlines are in agreement with findings from Muntohar (2011).

3.2 Discussion

The basis of the splitting tensile test is the Brazilian tensile test, which uses a specimen size with $H/D \leq 0.5$, it is commonly known as a "disk" size (Krishnayya and Eisenstein, 1974). In this case, the shear failure occurs below the load strip because of the stress concentration (Namikawa and Koseki, 2007). In this splitting tensile test, the strength Tu is calculated from the peak load by Equation (1), assuming the stabilized clay exhibits linear-elastic behavior. Consequently, the specimen is assumed to be homogenous-isotropic, and the splitting tensile strength decreases in accordance with the specimen size ratio (*H/D*). A higher *H/D* indicates slenderness, and the stiffness possibly decreases. This finding was also confirmed by Kim et al. (2001). Hence, from a point of view of the fracture mechanism, the specimen undergoes mode II (shearing) due to a likely 'flexural-effect' along the height (Andreev, 1991*a*,*b*; Atahan et al., 2005; Ruiz et al., 2000). The term of 'flexural effect' is defined in this study, since the loading is also controlled by the bearing strip (see Figure 3b) to distribute the applied load along the specimen height (Ince, 2017). Figure 5a shows a specimen without fibers after failure. The shear failure limits

(a)



(b)

Figure 5 The specimen after failure (a) without fibers, (b) with fibers

further increase in the applied load; consequently, the tensile strength calculated by Equation 1 decreases.

In contrast to the unreinforced specimen, the split tensile strength of the specimen with fibers shows a trendline that increases with the *H/D* ratio. Fibers in the stabilized clay act as reinforcement to prevent the specimen from developing macrocrack earlier. This mechanism enhances the ability of the specimen to transmit a higher load until it reaches failure. The improvement is achieved through the fiber 'bridging effect' (see Figure 5b), where the load carried out by the cracked zone is transferred to the fibers due to the significant interfacial binding strength between the fibers and the matrix. The more extended specimen size means the more extensive the volume of the specimen. Based on the probability principle, in a larger volume size, the fibers distribute more efficiently on the shear plane and increase the peak strength of the reinforced soil (Muntohar, 2009). In a large-sized specimen, more fibers reach the yield stress condition along the centerline rather than in small-sized specimens. This phenomenon can cause more energy to be released and more stress to be redistributed throughout the crack growth process inside a large specimen, resulting in a more noticeable fiber reinforcement effect. Therefore, the size effect of split-tensile strength is greatly impacted by the addition of fiber (Kazemi and Lubell, 2012; Yu et al., 2024).

As explained in previous studies, presently, there is still no standard size of specimens in splitting tensile strength tests for stabilized soil. This research has carried out two groups of tests; however, it is still challenging to determine the size of the test specimen or the correction factor for the ratio of size to tensile strength as formulated by Güneyli and Rüşen (2015). Further studies are needed to have a unique conclusion, such as failure patterns, stress concentration, and distribution (Güneyli and Rüşen, 2015), and size ratio (width and length) of strip bar bearings to test specimens (Bazant et al., 1991; Rocco et al., 1999), the density of the specimen, and cementation state (Consoli et al., 2010). However, based on the trendlines from Figure 4, it can be recommended that the specimen size affects the splitting tensile strength. The effect is lesser after the *H/D* ratio is greater than 2.5.

4 CONCLUSION

A series of experiments has been done successfully to investigate the effect of specimen size ratio (*H/D*) on the splitting tensile strength of stabilized and fiber-reinforced clay. It is noticed that the experiment is limited to the specimen *H/D* ratio from 0.5 to 2.5. According to the investigation, when the *H/D* ratio increases, the splitting tensile strength of the specimen without fibers decreases, while the specimen with fibers experiences an increase in splitting tensile strength. Adding fibers to stabilized clay can improve the splitting tensile strength by a factor of 2.4. The size of the specimen influences the splitting tensile strength. As the *H/D* ratio increases above 2.5, the effect becomes less pronounced. Even with the two test groups conducted in this research, it remains challenging to ascertain the specimen size or, at the very least, the correction factor for the size ratio -to-splitting tensile strength. A unique conclusion will require more detailed research on a number of topics, including failure patterns, stress concentration and distribution, the width and length ratio of strip bar bearings to test specimens, specimen density, and cementation state.

DISCLAIMER

The authors declare no conflict of interest.

ACKNOWLEDGMENTS

The research is possibly completed with support from the Ministry of Education through the fundamental research grant in 2011-2012 entitled "Engineering Behavior of Soils -Reinforced with Fibers and Stabilized with Cemented Materials". The counterpart funding from the Universitas Muhammadiyah Yogyakarta is highly appreciated.

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