http://journal.uir.ac.id/index.php/JGEET

E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 7 No 1 2022

RESEARCH ARTICLE

Effects of Corn Stalks Ash as A Substitution Material of Cement Due to the Concrete Strength of Rigid Pavement

Roza Mildawati [1,*], Anas Puri[1], M. Zaky Handayani[1]

[1] *Universitas Islam Riau, Civil Engineering Department, Jl. Kaharuddin Nasution 113 Pekanbaru, Indonesia*.

* Corresponding author: rozamildawati@eng.uir.ac.id
Tel.: +62 812-9085-1785
Received: Feb 27, 2020; Accepted: Feb 4, 2022.
DOI: 10.25299/jgeet.2022.7.1.4681

Abstract

Cement is an adhesive material for concrete mixtures in addition to water, fine and coarse aggregates. One of the main ingredients of cement is silica (SiO2) which is originated from the earth's crust. Silica is also available in plants such as corn stalks. This research is aimed to utilize the corn stalk ash (CSA) as an alternative substitution for some cement in concrete for the rigid pavement of road construction. According to the Indonesian standard, the flexural tensile strength should be exceeded at least 4.5 MPa. The flexural tensile strength has also a correlation due to compressive strength.

The concrete materials consisted of the coarse aggregate (river crushed stone) from Kampar River and Danau Bingkuang sands from Kampar District of Riau Province, and Portland Composite Cement from Semen Padang. The CSA was made by burning the dried corn stalks in a steel cylinder can over 24 hours. The content of CSA was varied by 0%, 5%, 7% and 9%. The compressive strength design of concrete was 31,3 MPa. Testing procedures were based on the Indonesian Standard for concrete. The tested specimens have consisted of cube specimens (150 mm x 150 mm x 150 mm) for compressive tests, and beam specimens (150 mm x 150 mm x 600 mm) for flexural strength tests. All specimens were tested on 28 days-age.

The results show that CSA can be used as a partial substitution of cement in concrete. The addition of CSA tends to increase the compressive strength of concrete instead of its flexural tensile strength. The optimum content of CSA was 7% and resulted in an 8.0% and 6.9% increase in compressive and flexural tensile strength due to design respectively. Compressive and flexural tensile strength fulfilled the standard. Flexural tensile strength is obtained by 15% of the compressive strength. Cornstalk ash can be used as a substitution of cement for rigid pavement concrete. It can reduce the utilization of cement and will be potentially cost efficiency.

Keywords: Compressive Strength, Flexural Strength, Optimum Content, Rigid Pavement, Cement Substitution

1. Introduction

Concrete is a mixture of water, Portland cement or hydraulic cement, aggregate coarse and fine aggregates, with or without additives or mixtures (SNI 03-2847-2013, 2013) . A concrete structure can be defined as a building located above the ground with or without reinforcement (ACI 318-89-1990, 1990).

Concrete becomes one of the alternative materials in building construction, both in road construction and construction, in addition to the use of metal and wood, which has been known as one of the bad properties of concrete can be seen from the strength of the strength and flexural strength, increased strength and flexural strength so that the better concrete performance. Where a concrete mixture consisting of coarse aggregate, fine aggregate, cement, fly ash and other addictive materials.

One of the concrete mix materials is cement, while cement which is often used is Portland cement. Portland cement is one type of hydraulic cement, while the main ingredients in making Portland cement are lime (CaO), Silica (SiO2), alumina (Al2O3), magnesia (MgO), and alkalis (Mulyono, 2004). Silica (SiO2) is one of the important components in the composition of cement. Silica is extracted from the earth's crust but can also be found in plants in large numbers. The shape of the silica plant that is found in the form of quartz or crystalline silicon (Buol et.al, 1980). Corn is one of the types of agricultural crops that have the largest yields. In addition to corn cobs, corn stalks are also waste from agriculture. In agricultural activities will produce 19.13% of waste obtained from stems and leaves. Corn stalk ash has a silica content of 67.41%, the silica content of corn plants increased more than no other macros such as N, P, K, Ca, Mg and S (Majedu, 2014).

Research about the utilization of corn bark ash for additional admixture in concrete has been done by Chandra (2013) , and corn cob ash for substitution of some cement in concrete also done by Oladipupo (2012). Dewi, et.al (2019) also used corn stalk ash and Sikament NN additive as a substitution of some cement in concrete. Their research focused on the compressive strength of concrete especially concrete for general purposes.

Pekanbaru is one area that grows sweet corn and has the rest of the sweet corn stalks that are not used. Then the researchers are interested in conducting research on the utilization of sweet corn stalk ash on compressive strength and flexural strength of concrete. This research is aimed to utilize the corn stalk ash (CSA) as an alternative substitution for some cement in concrete for the rigid pavement of road construction. Can the CSA as a concrete admixture and fulfill the minimum standard of the flexural tensile strength for rigid pavement material.

2. Methodology

2.1 Research Methods

The analysis carried out in the research on compressive strength testing on cylindrical objects and cube specimens refers to SNI 03-2834-2000, while research on flexural tensile strength tests on beams refers to SNI 03-4431-2011. Research on the compressive strength of concrete for cylinder and cube specimens refers to SNI 03-1972-1990. The first stage of the analysis consists of checking the material of the test object, namely checking aggregates, checking water content, checking specific gravity and material absorption, checking mud content, checking bulk density. Then the second stage consists of checking the concrete including the results of the mix design, checking the slump value, checking the compressive strength and flexural strength of the concrete with the substitution of sweet corn stalk ash on the weight of cement. And the last stage consists of analysis of concrete testing.

2.2 Concrete

Concrete is defined as a mixture of ingredients consisting of hydraulic materials (portland cement), coarse aggregate, fine aggregate, and water with or without the use of materials additional (SNI 03-2847, 2013). As the age increases, the concrete will harden and will reach strength (f'c) at the age of 28 days. Concrete has compressive strength that is good, therefore concrete is widely used or used for various types of structures, especially bridge and road structures.

Concrete has a high compressive strength but is weak against strength pull. High-strength concrete has a strength between 35-65 MPa (K400-K800) is generally used for prestressed concrete such as prestressed concrete piles, prestressed concrete girders, prestressed concrete slabs and the like (Pd T-07-2005-B, 2005).

2.3 Rigid Pavement

Portland cement concrete road pavement or more often called Rigid pavement or also called rigid pavement, consists of cement concrete slab portland and the foundation layer (maybe not present) above the subgrade. Pavement stiff road and has a high modulus of elasticity, will distribute the load over a large enough land area, so that the largest part of the pavement structure capacity is obtained from the concrete slab themselves (Sukirman, 2013).

The advantages of rigid pavement over flexible pavement (asphalt) is how the load distribution is transmitted to the subgrade. Rigid Pavement because it has stiffness (stiffnes), will distribute the load on the area which is relatively wide in the subgrade, the concrete itself is the main part that bears the structural loads, while flexible pavements are made of materials that less rigid, then the spread of concrete is not as good as in concrete, so it requires a larger thickness (Tenriajeng, 1999).

2.4 Concrete Strength

The compressive strength of concrete is the magnitude of the load per unit area, which cause the concrete test object to crumble when loaded with a certain compressive force, produced by the press machine (SNI 03-1974-1990, 1990). Compressive strength of concrete begins by the maximum stress when the concrete has reached the age of 28 days. Concrete designed must meet the requirements of the average compressive strength, which meets requirements based on standard deviation data from compressive strength test results for conditions and types the structure that is retained in the fourth sieve is called coarse aggregate and whose grains are smaller than 4.75 mm or pass through the sieve number four is called fine aggregate.

Flexural strength is the ability of a concrete block to be placed in two bearing to withstand the force in a direction perpendicular to the axis of the test object, which given to him, until the test object breaks, expressed in Mega Pascal (MPa) force per unit area (SNI 4431-2011, 2011).

2.5 Concrete Material

(1) Portland Cement

Portland cement which was originally discovered in near the city of Dorset, England, is a commonly used material for these needs (Dipohusodo, 1999). Portland cement is made from fine powder crystalline mineral whose main composition is calcium and aluminum silicate.

(2) Water

Water is needed in the manufacture of concrete to trigger chemical processes cement, wets the aggregate and provides convenience in concrete work.

(3) Aggregate

aggregate is material granular materials such as sand, gravel, crushed stone as a result of natural disintegration produced from the stone crushing industry which has the largest grain 0.5 mm for fine aggregate. While coarse aggregate has a grain size between 5 mm up to 40 mm (SNI 03-2847-2002, 2002)

(4) Additional Ingredients

Auxiliary minerals are currently being added to the mix concrete for various purposes, including to reduce the use of cement, reduce temperature due to hydration reaction, reduce bleeding or increase the workability of fresh concrete. How to use it is also different, as substitute or as an addition to the mixture to reduce use of aggregates (Nugraha, 2007) . Additional ingredients are ingredients added to the concrete mix at the time of or during mixing take place. The function of this material is to change the properties of the concrete to be more suitable for a particular job, or to save costs (Mulyono, 2004). Corn stalk ash is the ash produced by burning corn stalks pass filter No. 200. The components of old and ready-to-harvest corn plants consist of: 38% seeds, 7% cobs, 12% bark, 13% leaves and 30% stems. Corn is 17 one of the plants that have the largest waste in Indonesia. Apart from cob corn, corn stalks are also waste from agriculture. Plant waste Corn, mainly in the form of stems, leaves, skin, cobs or cob reaches 1.5 times the weight of the seeds means that if 8 tons of seeds are produced per hectare then all at once obtained 12 tons of waste made. The stems of corn plants are dense, the thickness of the corn stalk is about 2 – 4 cm depending on the variety. Genetic have a high effect on plants. Very tall plant This varied character is a very influential character in the classification character of corn plants (Ervina, 2013). Corn is plants containing silica. Corn plants have silica content 20.6% which exceeds the macronutrients N, P, K, Ca, Mg and S (Yuwono, 2001).

2.6 Selection of Material Types

The materials used in this research are outlined below.

(1) Coarse Aggregate
The coarse aggregate used is crushed stone from the Kampar river.
(2) Fine Aggregate
The fine aggregate used is Banau Bingkuang Kampar sand.
(3) Water
The water used comes from bore wells from the Faculty of Engineering, Riau Islamic University, Pekanbaru, Pekanbaru City.
(4) Cement
The cement used is Portland PCC cement from PT Semen Padang.
(5) Additional Ingredients
The material used as a partial substitute for cement is corn stalk ash, specifically sweet corn.

In this research, supporting equipment is needed. The equipment used in this research are outlined below.

(1) Grail
This tool is used to place the test object before carrying out the previous test. The cup is made of heat-resistant aluminum. Different sizes are used.
(2) Oven
The oven used is Onky Heraeus which is equipped with a temperature setting. The temperature used in this study was 110±5◦ C.
(3) Awl Rod
The awl used is made of steel with a length of 60 cm and a diameter of 16 cm.
(4) Hammer
Hammer made of iron with wooden handle
(5) Ruler
Ruler used to measure diameter, slump drop made of steel.
(6) Sieve
Sieve used to sieve coarse aggregate and fine aggregate in order to obtain a sieve analysis. The filter sizes used are 11/2, ,3/8, No.4 (4.8 mm), No.8 (2.4 mm), No.16 (1.2 mm), No.30 (0 .6 mm), No.50 (0.3 mm), No.100 (0.15 mm), No.200 (0.075 mm)
(7) Container
A cylindrical container made of steel with a height of 155 mm and a diameter of 158 mm. Used for checking the density of fine aggregate and coarse aggregate.
(8) Scales
The scale must have an accuracy of 0.3% of the weight being weighed or 0.1% of the maximum capacity of the scale. The scales used are manual scales with a capacity of 20 kg and automatic scales with a capacity of 2 kg.
(9) Pycnometer
The pycnometer used is Iwaki CTE33 500ml, made of glass that has a pointer scale which will be used as a measuring tool.
(10) Slump Uji Test Equipment
This tool is made of conical steel with a thickness of 2 mm, an upper diameter of 100 mm and a lower diameter of 200 mm.
(11) Concrete Mold
The concrete mold is made of steel. In this study, the researchers used a cylindrical mold with a height of 300 mm and a diameter of 150 mm which was used to print concrete after mixing fresh concrete.
(12) Vibrating Machine
The vibrating machine functions to compact the fresh concrete that has been inserted into the mold and also to remove the air that is in the mold.
(13) Beheaded Cone
The truncated cone is used when testing the specific gravity of the fine aggregate, which is to check the dry state of the saturated surface of the fine aggregate. Made of steel with a top diameter of 35 mm and a bottom 80 mm, a height of 70 mm and a thickness of 1 mm.
(14) Concrete Compressive Strength Machine.
The concrete compressive strength machine is used to test the compressive strength of concrete. The machine used is BT Testing with manual dial. This tool is made of steel and has load control and regulation.
(15) Concrete Bending Strength Machine
(16) Concrete Mixer Machine
The concrete mixer used is Tiger with a capacity of 125 liters. This machine is used to mix the ingredients for making concrete.
(17) Soaking Tub
The soaking tub serves to treat the concrete that has been printed, the concrete is soaked according to the planning day.
(18) Iron Drum
Iron drums are used as a place to burn corn stalks to ashes.

2.7 Concrete Mix Design in SNI 03-2834-2000

The requirements for the planning method of SNI 03-2834-2000 are as follows:

1. Planning the required compressive strength (f_c') at the age of 28 days. The planned concrete must meet the requirements for average compressive strength ($f_c'r$).
2. Standard deviation (S).

Deviation measuring instrument is a measure of the quality level of the implementation of the manufacture (production) of concrete. Standard deviation is the identification of deviations that occur in the data group in this case concrete production. This S value is used as one of the input data in the planning of the concrete mix. The formula for calculating the standard deviation is as follows (Mulyono, 2004).

$$S=\sqrt{\frac{\sum_{i=1}^{n}(xi-x)^2}{n-1}} \quad (1)$$

Where:
S = Standard deviation
Xi = compressive strength of concrete used from each object test
X = Average concrete strength
n = Number of test objects as a result of inspection

The following is the standard deviation to find the level of concrete quality control whether it is good or not.

Table 1. Standard deviation value for indication of level of concrete quality control (Mulyono, 2004)

Standard deviation	Concrete Quality Control Level Index
2,8	Very Satisfy
3,5	Satisfying
4,2	Good
5,6	Enough
7,0	Bad
8,4	Without Control

3. Added Value (Margin)

The added value is calculated by the formula:

$M = K \times S$ (2)

Where:

M = Value added margin (N/mm^2)

K = 1.64 is a statistical determination whose value depends on the percentage lower than fc'. In this case, 5% is taken, so the value of k = 1.64

S = Standard deviation (N/mm^2).

After getting the added value of the margin, continue calculating the average compressive strength ($f_c'r$).

4. Calculation of the targeted average compressie strength (fc'r).

The planned average compressive strength is calculated by the formula:

fc'r = fc'+ M 3.20 (3)

Where:

fc'r = Average compressive strength (MPa)

fc' = Planned compressive strength of concrete (MPa)

M = Value added or Margin (MPa)

5. Determine the type of Portland cement used.

6. Determine the type of aggregate to be used. Both fine aggregate and coarse aggregate.

7. Determining the Water Cement Factor (FAS)

Water-cement factor is the ratio of the weight of water to the weight of cement used in the concrete mix.

8. Determination of the maximum Cement Water Factor (FAS)

This determination is based on the minimum amount of cement with the maximum water cement factor for various types of concrete mix designs.

9. Determination of slump value.

10. Determination of the maximum aggregate size.

11. Free moisture content, to determine the free moisture content of the combined aggregate in the form of a mixture of a mixture of natural sand and gravel (crushed stone), the free moisture content must be calculated between 160-190 kg/m^3 (if the slump is 30-60 mm and the maximum size line is 30m. Calculations can be done with the following equation:

$\frac{2}{3} Wh + \frac{1}{3} Wk$ (4)

Where:

Wh = water estimate for fine aggregate

Wk = water estimate for coarse aggregate

12. Calculating the amount of cement in step 11, and step 8. Amount of water/phase

13. Maximum cement quantity is ignored if not specified.

14. Determine the minimum amount of cement. The weight of cement obtained from step 11 must be greater than the minimum requirement.

15. Determine the adjusted water-cement factor.

16. Determine the number of fine aggregates, in accordance with the requirements of SK 03-2834-2000.

17. Determine the percentage of fine aggregate to the mixture based on the slump value, water-cement factor and the maximum nominal aggregate.

18. Calculating the relative density of aggregates

BJ. Mixture = ($\frac{P}{100}$ x BJ fine aggregate) + ($\frac{K}{100}$ x BJ coarse aggregate) (5)

Where:

P = Percentage of fine aggregate to mixed aggregate (%)

K = Percentage of coarse aggregate to mixed aggregate (%)

BJ = Specific Gravity

19. Determine the specific gravity of the concrete, based on the type of aggregate combined and the value of the free moisture content, step 11.

20. Calculate the combined moisture content, i.e. the specific gravity of the concrete minus the cement content and moisture content, steps 19-15-11

21. Calculate the fine aggregate whose magnitude is the combined aggregate content times the percentage of fine aggregate in the mixture, steps 20-16.

22. Calculate the coarse aggregate content, combined aggregate minus the coarse aggregate content, steps 20 and 21.

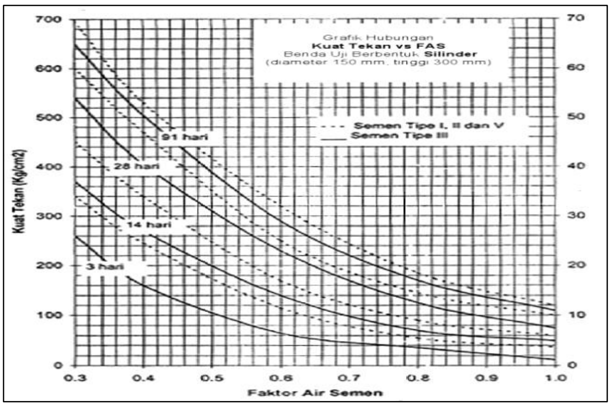

Fig. 1: The relationship between the compressive strength of concrete and the water-cement factor of cylindrical specimens 150 mm x 300 mm (SNI 03-2834-2000)

Estimated compressive strength (MPa) of concrete with a cement water factor of 0,5 and the type of coarse aggregate commonly used in Indonesia

Table 2. Estimated compressive strength (MPa) of concrete with a cement water factor of 0.5 and the type of coarse aggregate commonly used in Indonesia

Cement Type	Aggregate Type Rough	Compressive Strength (MPa) At Age (Days) 3	7	28	91	Test Object Shape
Portland cement type 1 or sulfate resistant cement type II and IV	Unbreakable stone broken stone	17 18	23 27	33 **37**	40 45	Cylinder
	Unbreakable stone broken stone	20 23	28 32	40 45	48 54	Cube
Portland cement type III	Unbreakable stone broken stone	21 25	28 33	38 44	44 48	Cube
	Unbreakable stone broken stone	25 30	31 40	46 53	53 60	Cube

This research was conducted at the Laboratory of Concrete, the Faculty of Engineering, Universitas Islam Riau (UIR). The materials used were the Danau Bingkuang sand, crushed stone of Kampar River, Portland Composite Cement (PCC) from Semen Padang, freshwater and corn stalk ash. The particle size distribution of sand is shown in Fig.1 which fulfilled zone II in Indonesian Standard. The maximum particle size of the crushed stone was 40 mm. The mud content and water content of all aggregate less than 1.0%. The compressive strength design of concrete was f_c' = 32 MPa. The minimum flexural strength of concrete for rigid pavement is 4.75 MPa. Table 3 shows the result of a mixed design of concrete. The values were not yet corrected due to SSD (saturated surface dry) of aggregates. The w/c ratio was 0.37. The workability target was 60 mm – 180 mm.

This research stage was the material preparation, testing material properties, mix design, concrete mixing, slump test, manufacturing the test specimens, conducting the concrete compressive strength and flexural tensile strength tests, data analysis, discussion of analysis results, reporting the research and publishing the articles.

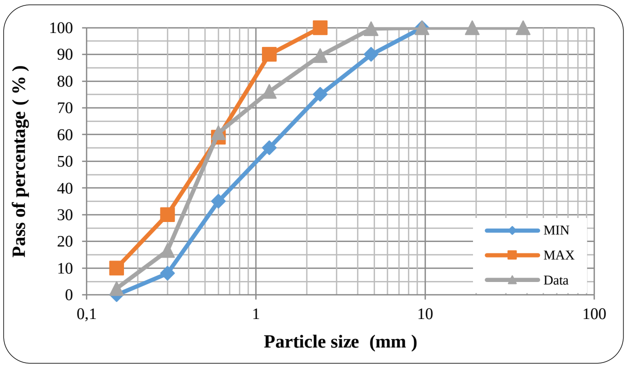

Fig. 2: The particle size distribution of sand (zone II categorized).

The specimens for compressive strength tests were a cubic shape with dimension 15 cm x 15 cm x 15 cm and for flexural tensile strength, tests were a beam shape with dimension 15 cm x 15 cm x 60 cm.

Table 3. Concrete mixture combinations for each m3.

Descriptions	Cemen (kg)	Water (ltr)	Sand (kg)	Crushed stone 2/3" (kg)	Crushed stone 1/2" (kg)
Each m3	528,571	185	575,522	313,154	469,731
Each 1 zak of cement	50	17,5	54,441	29,622	44,434
Each of mixture components	1	0,35	1,088	0,592	0,888

3. Results And Discussion

3.1 Effects of CSA Due to the Workability of Fresh Concrete

The workability of fresh concrete was tested by the slump test method. The value of slump tests is shown in Fig.3 and 4 for specimens test of compressive and flexural strength respectively. All slump values were not fulfilled the design target. Slump values tend to decrease by increasing the CSA. Fresh concretes tend to difficult to be worked. Similar results were found by Dewi, et.al (2019).

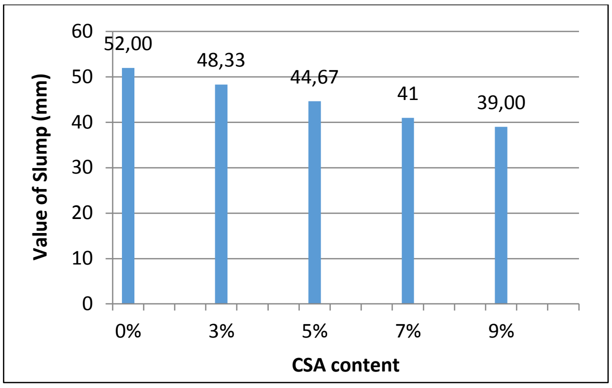

Fig. 3: Relationship of slump value and CSA content for compressive strength test specimens.

3.2 Effects of CSA Due to the Compressive Strength

The addition of CSA affected insignificantly the compressive strength of concrete (Fig.5). The compressive strength increased only about 1.8% – 5.7% from the design value. The optimum content of CSA was 7%. Dewi, et.al (2019) also found that the CSA has an insignificant effect on the compressive strength. Based on these results, it is evident that the CSA can substitute some of the cement content in the concrete. It is beneficial to use in the field.

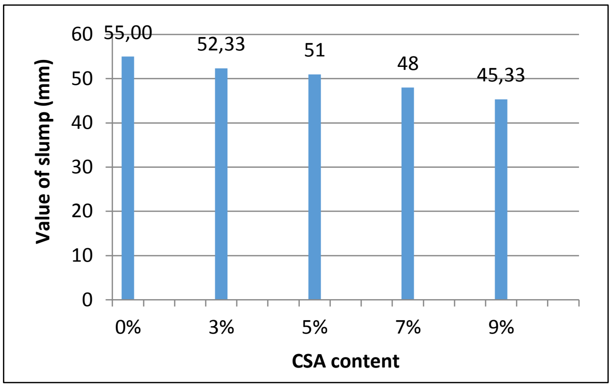

Fig. 4: Relationship of slump value and CSA content for flexural tensile strength test specimens.

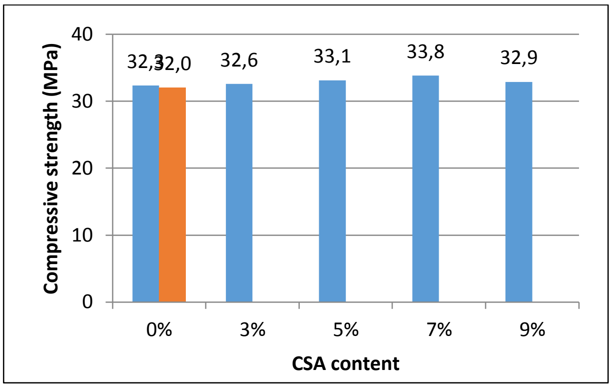

Fig. 5: Effects of CSA due to the compressive strength of concrete.

3.3 Effects of CSA Due to the Flexural Tensile Strength

The effects of CSA due to flexural tensile strength are similar to the compressive strength. The addition of CSA affected insignificantly the flexural tensile strength of concrete (Fig.6). The flexural tensile strength increased only about 2.9% – 6.9% from the design value (4.75 MPa.). The optimum content of CSA was also 7%. Based on these results, it is evident that the CSA can substitute some of the cement content in the concrete. The minimum standard of 4.75 MPa. flexural tensile strength for rigid pavement was fulfilled. It is beneficial to use in the field. CSA can reduce the utilization of cement. Since the prize of cement is cheapest compare to other concrete materials, substitution the cement content can reduce the cost of concrete.

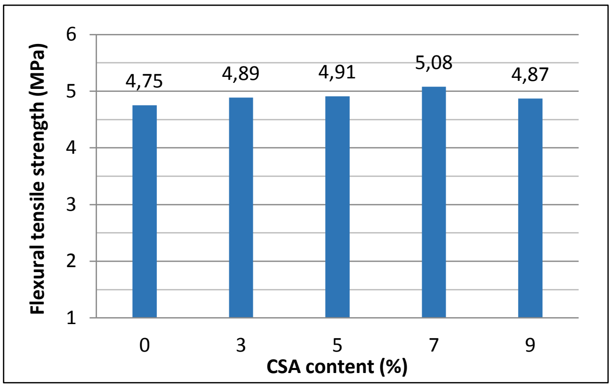

Fig. 6: Effects of CSA due to the flexural tensile strength of concrete.

The comparison between flexural tensile strength and compressive strength of concrete is shown in Fig.7. The flexural tensile strength was about 14.7% - 15.0% of the compressive strength.

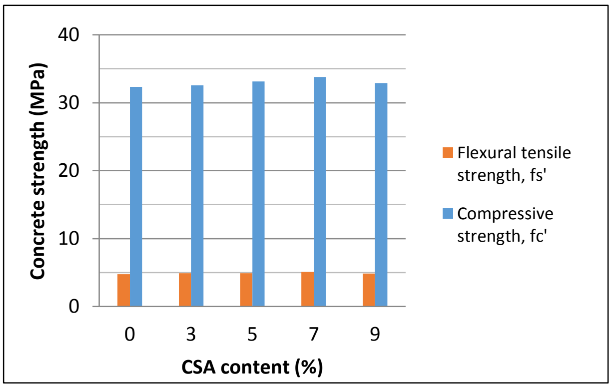

Fig. 7: The comparison between flexural tensile strength and compressive strength of concrete.

4. Conclusions

According to the results, it can be concluded that the CSA can be used as a partial substitution of some cement in the concrete. The addition of CSA tends to increase the compressive strength of concrete instead of its flexural tensile strength. Compressive and flexural tensile strength fulfilled the standard. Flexural tensile strength is obtained by 15% of the compressive strength. Cornstalk ash (CSA) can be used as a substitution of cement for rigid pavement concrete and can increase the compressive strength of concrete instead of its flexural tensile strength. about 5%. CSA can reduce the utilization of cement and will be potentially cost efficiency.

Acknowledgment

Authors to thanks for supporting by Research Institute and Community Services (LPPM) with contract number 698/KONTRAK/LPPM-UIR/5-2019 and the Laboratory of Civil Engineering of Universitas Islam Riau.

References

ACI 318-89, 1990. (1990). *Building Code Requirements for Reinforce Concrete, Part I, General Requirement, Fitth Edition. Skokie, Illinois, USA: PCA.*

Badan Standardisasi Nasional. (1990). SNI 03-1974-1990 Metode Pengujian Kuat Tekan Beton. *SNI 03-1974-1990*.

Dipohusodo, I. (1999). *Struktur Beton Bertulang Berdasarkan SK SNI T- 15-1991-03. Jakarta: PT. Gramedia Pustaka Utama*.

Ervina. (2013). *Isolasi Silika Dari Tongkol Jagung, Tugas akhir, Universitas Pembangunan Nasional, Surabaya*.

Et.al, B. (1980). *Food Comotition and Analysis, p.122-123,AVI Publishing, New York*.

Majedu, K. A., S. A. A. and I. O. L. (2014). *The Use of Corn Cob Ash and Saw Dust Ash as Cement Replacement in Concrete Works. The Internasional Journal of Engineering and Science (IJES) Vol. 3 No. 4. Federal Polytechnic Ede : Osun State.*

Mulyono, T. (n.d.). *Teknologi Beton, Edisi Kedua, Andi, Yogyakarta. 2004*.

Nugraha, A. dan P. (2007). *Teknologi Beton. Penerbit C.V Andi Offset, Yogyakarta.*

Pd T-07-2005-B. (2005). Pelaksanaan pekerjaan beton untuk jalan dan jembatan. *Badan Penelitian Dan Pengembangan PUPR*, 1–21.

Sukirman, S. 2003. (2013). Persyaratan Beton Struktural untuk Bangunan Gedung. In *Bandung: Badan Standardisasi Indonesia*.

SNI 4431-2011, S. (2011). *Cara Uji Kuat Lentur Beton Normal dengan Dua Titik Pembebanan*.

Tata Cara Perhitungan Struktur Beton Untuk Bangunan Gedung. SNI 03-2847-2002. (2002). *SNI 03-2847-2002*, 251.

Tenriajeng. (1999). *Perkerasan Kaku Jalan Raya* 2013–2015.

Yuwono, R. dan. (2001). *Kesuburan dan pemupukan tanah pertanian", Pustaka Buana, Bandung*.