TENSILE STRENGTH PROPERTIES OF NORMAL STRENGTH CONCRETE DUE TO LOADING TYPE AND SPECIMENS SIZE

I Nyoman Merdana[1], Fathmah Mahmud[1]
[1]Departement of Civil Engineering Facullty of Engineering, University of Mataram
E-mail: nmerdana@unram.ac.id

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ABSTRACT

Various size of Concrete cylinder come across often in any project site and the most simple and common method in obtaining the tensile strength of concrete is Splitting test. This study is to find out the influence of concrete cylinder size and loading type on behavior of splitting tensile strength of normal weight concrete. In this study height-diameter ratio h/d, Wide of load spreader t - radii of concrete cylinder r ratio (t/r) and diameter of the concrete cylinder as well are considered as variables. The current study was experimentally focused on behavior of Splitting Tensile strength of normal concrete. Specimens were concrete cylinder having compression strength f'c=25MPa and mix proportion was constant, namely 1:2:3 of cement-sand-crushed stone by volume with a constant water-cement ratio of 0.45. Cylinder depth to diameter ratios of the specimens was varied between 1 and 3. Data collected indicate that the wider the load spreader the higher the splitting tensile strength of the concrete. This is presumably due to changes in the load pattern from line-loads to evenly distributed-loads, and this phenomenon needs to be explored further. The load applied on the concrete specimens with wide spreader have a likelihood to be distributed one. Splitting tensile strength rises nonlinearly as the t-r ratio increase. The smaller the diameter of the specimens, the higher the splitting tensile strength gained

Keywords: *Normal strength concrete, Height-diameter ratio, Splitting tensile strength, Loading type, Specimen size*

INTRODUCTION

Concrete as dominant structural material in every part of the world is no doubt. Actually, the usage of concrete as structural material is because of the fact that, concrete constituent is easy to find, concrete making is relatively easy to handle, it provides a good fire resistance, and does not need costly maintenance. Broadly speaking, concrete is utilized in every civil construction. (MagGregor (1997), Wight and MacGregor (2012)).

In design stage, properties of concrete play important role. The properties are, such as Compressive strength f'_c, Tensile strength f_t, Modulus of elasticity E_c, Stress-strain relationship, etc. It is known that concrete is strong in compression, but in the other hand, concrete has low tensile strength, just about 10-12% of the compressive strength. (MacGregor, 1997)

Cracking behavior of concrete and minimum amount of steel reinforcement of structural element is governed greatly by the Tensile strength of concrete. Usually, the Tensile strength of concrete is determined by indirect test, namely splitting tensile test and Modulus of rupture test according to ASTM C496-11 and ASTM C78-90 respectively. Direct tension test is rarely carried out in determining tensile strength of concrete because of difficulty in applying axial tension load to a concrete specimen. Consequently, the choice of which method to be used to discover the tensile strength is simply based on the simplicity of the method. The most common method used in Indonesia is The Splitting test. Based on ASTM C496-90, Splitting test is carried out by applying compressive load on a concrete cylinder of the type used in compressive strength testing, placed horizontally. The applied load is spread through narrow strips of packing material, such as hardwood or plywood, which is inserted between the specimen and the platen of the testing machine. In fact, the tensile test is frequently performed by applying the load directly on the surface of the specimen instead of using the spreader strips as shown in Figure 1 (c). Therefore, a very high stress exists between surface of the specimen and the platen. This condition will affect the Tensile strength obtained from the test. Considering the reality, this current study is intended to disclose the influence of loading type on the Tensile strength of concrete.

In concrete structures, quality control is usually based on the test of concrete cylinders, cubes. To assess the quality of existing concrete structures or the actual strength of concrete in a structure; core drill testing is one of the methods that can be used. The various specimen size influences the Tensile strength obtained from the test. The concrete behavior corresponding to the various specimen size is recognized as Size effect. The Tensile strength behavior of concrete regarding to the size effect phenomenon is need to be disclosed.
In this regard, it is essential to study the behavior of tensile strength concerning to the size effect and loading type used in testing.

There is relation uniquely between compression strength and Tensile strength, in spite of the fact that it does not has a direct proportionality. The strength of concrete is controlled by several secondary factors for instance specimen size, loading type, curing history and moisture content as well. (MacGregor, 1997, Neville (1997), Wight and MacGregor (2012)).

Compressive strength f'c, determined through compression loading on 150mmx300mm concrete cylinders according to ASTM C39-93, has been always referred to concrete quality. Moreover, tensile strength is one of key properties of concrete as well. The tensile strength is indeed very important to be explored as it relates directly to both cracking behaviors of a structure and Fracture toughness as well as fracture energy. Tensile strength of concrete is often determined as a percentage of compressive strength, and therefore, practically, direct tensile strength test is rarely carried out because of difficulties in applying axial tension load.

The tensile strength f_t is frequently found out by Splitting tensile test according to ASTM C496-11 or SNI 2491-2002. Then tensile strength obtained by splitting test can be calculated from equation (1) and the test using point-line load or distributed load is shown in figure 1. Referring to ASTM C496-11, splitting strength test conducted in which load applied on the concrete specimen is spread out through a limited contact surface called Bearing strips, as shown in Figure 1(c). The load rate is applied as constant as possible around 0.011-0.23 MPa/s.

The Size effect phenomenon is investigated by comparing the behavior of geometrically similar specimens. The study has been carried out only based on data collected experimentally, but recently the data have been correlated with various approximations and models. It is shown by many researches that nominal strength of concrete decrease with increasing size of structures. Zaitsev and Kovler (1986), Neville (1996), (Alca et.al (1997), Bazant and Planas (1998), Kim et.al (1999), Krauthammer et.al (2003), Merdana (2006), Hamad (2017), Mardani (2021) and also Domagala (2021). Almost all of the researches mentioned were performed on high strength concrete instead of on normal strength concrete

Domagala, (2021) through experimental study with lightweight concrete cored and molded concrete specimens, concluded that the strength measurements did not appear to be affected by slenderness or core diameter. This can be explained by the fact that the tested lightweight concretes have significantly better structural homogeneity than that of normal-weight concretes. Nonetheless, the results obtained on molded and cored specimens of the same shape and size showed considerable variances.

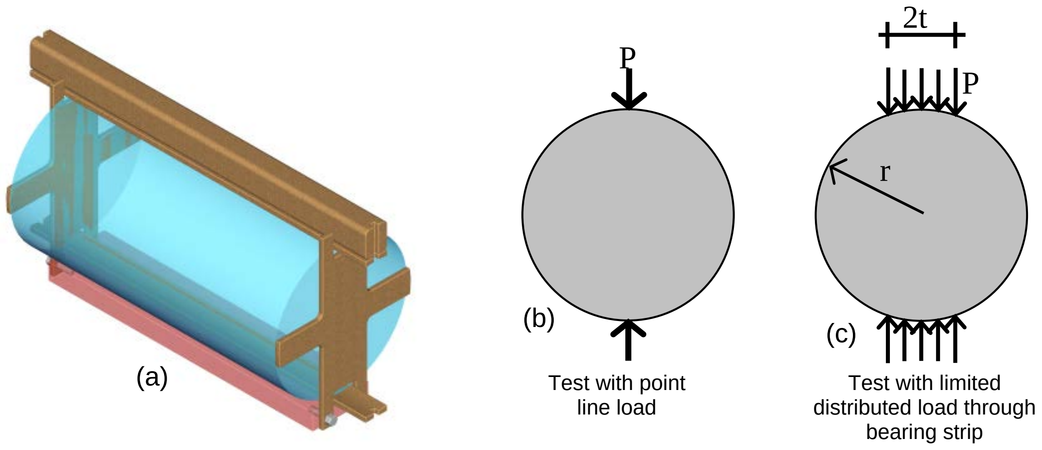

Figure 1. Splitting strength test apparatus. Isometric view (a), Splitting test with point-line loading (b) and idealized narrow distributed-load with Bearing Strips (c)
(Adopted from ASTM C496-90 and Tang (1992))

To understand profoundly the behavior of concrete splitting tensile strength, it is necessary to investigate influence of loading type and of size on the tensile strength. As mentioned in the background and Literature review recently therefore purpose of this study is to reveal behavior of Splitting tensile strength of concrete with regard to the size and the loading type effect used in testing, namely point-line load and distributed load on a given narrow contact area.

METHODS

Raw materials and mix design

As fine aggregate, river sand collected from Gebong River, sub district Narmada, West Lombok is utilized in design of mix proportion. Based on preliminary study conducted the Fineness modulus, Bulk specific gravity, and Average water absorption, were 3.3, 2.35, and 3.52% respectively. In addition, the loose densities and compacted densities of the sand were 1205 kg/m^3 and 1434 kg/m^3 respectively which can be classified as normal weight sand. Moreover, the grading curve for the fine aggregate tested according to ASTM is shown in Figure 2.

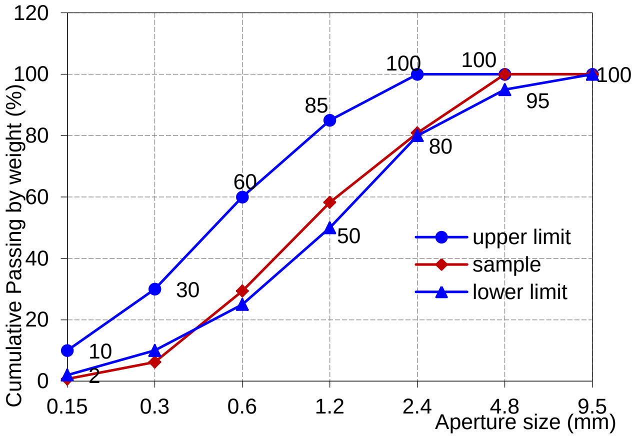

Figure 2. Sand Grading Curve based on ASTM Specification

On the other hand, in this study, nominal maximum size of coarse aggregate used was 20mm. The Loose bulk density, average Bulk specific gravity SSD and the Water absorption are 1205/m^3, 2.67 and 1.68% respectively. The mix proportion applied based on mass can be found in Table 1 with constant water-cement ratio namely 0.45. Detail of concrete specimens can be referred Table 2. In addition, the grading curve of crushed stone used in this study can be referred to Figure 3.

Table 1. Summary of Concrete mix design

Ingredients	Volume	Unit
PC	451.111	Kg/m^3
Sand	835.459	Kg/m^3
Gravel	893.261	Kg/m^3
Water	210.278	Liter

Figure 4 depicted the stages of this research in general. Before the test, weight of all concrete cylinders was recorded, and diameter and length of the specimens were measured as well. The diameter and length of the concrete cylinder used for calculating the tensile strength of the test specimens were determined by averaging two diameters measured at right angles to each other. The splitting tensile strength is obtained from equation (1)

$$f_t = \frac{2P}{\pi LD} \qquad (1)$$

Where:

f_t=splitting tensile strength (MPa)
P=maximum load (N)
L= length of concrete cylinder (mm)
D=diameter of concrete cylinder (mm)

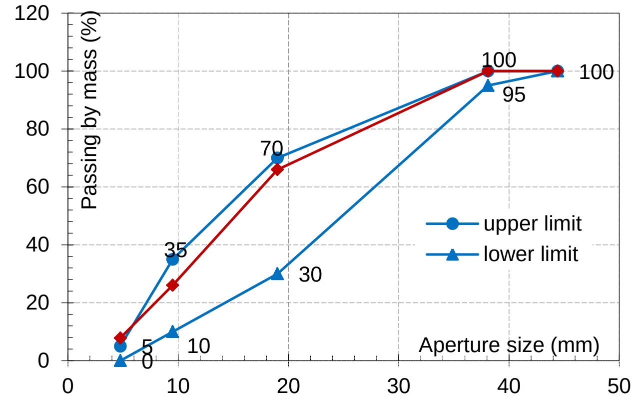

Figure 3. Gravel Grading Curve based on ASTM Specification

Concrete specimens

Cylinder depth to diameter ratios of the specimens was varied between 1 and 3. More detail information about the specimen can be referred to Table 2. In order to find easy identification, each concrete specimen is designated with an alphabet and three numeric pairs separated with hyphens. The letter T represents concrete cylinder for tension test. Then the number-pairs represent diameter of the concrete cylinder in mm, height-diameter ratio of the cylinder, and t-r ratio of the cylinder respectively. For instance, a specimen coded with *T150-20-10* is a concrete cylinder specimen intended for Splitting test with the diameter of 150 mm, height-diameter ratio of 2.0 and the t-r ratio of the cylinder of 0.1. The definition of t/r represented in Figure 1(c) is ratio of a half of contact width to the radius of cylinder. The specimen applied in this study can detailly be referred to Table 2.

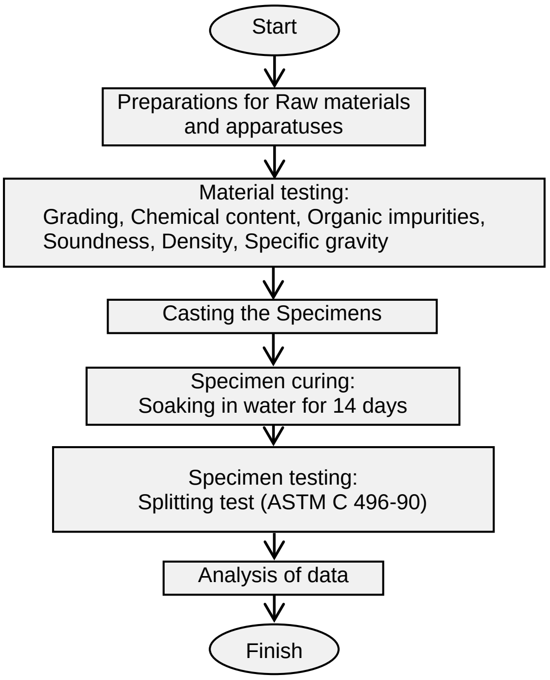

Figure 4. Flow chart of the research process

RESULTS AND DISCUSSION

The tensile test conducted in this study was indirect tensile test, namely splitting tensile test complying with ASTM C 496-90. All concrete specimens were various concrete cylinders, and tested at the same age, namely 28 days after casting. All specimens were also found similar curing treatment per ASTM C192-90. The concrete cylinders were immersed under water for 14 days followed by 14 days drying at room temperature.

Typically, current data collected indicates that the splitting tensile strength increases nonlinearly as the t-r ratio increase. This phenomenon is shown in Figure 5. The splitting tensile strength decrease at first and then increase nonlinearly as the t-r ratio increase. This trend is slightly different from former study conducted by Merdana (2006) and Tang (1992). The former study showed that the splitting tensile strength increased as the diameter of cylinder decrease. Note that the study was conducted his research with lightweight concrete.

The influence of *h/d* ratio on splitting tensile strength of concrete cylinders is shown in Figure 5 as well. From Figure 5, it can implicitly be stated that the highest splitting tensile strength is given by specimen with h/d=1. Based on the data observed, it is obvious that the smaller the diameter of the specimens, the higher the splitting tensile strength. Therefore, the splitting tensile strength decrease nonlinearly as the h/d increase.

Generally, according to Griffith and Weibull's theory, a material's fracture begins with any critical flaw (the weakest chain) present. As a result, specimens with bigger volumes have a higher likelihood of containing such a flaw and, as a result, have lesser strength. Furthermore, it is widely known that when the material is less homogeneous, the scale effect is more severe. Domagala, 2020; Bazant, 2004). The distribution of inclusions (aggregate) in the cement matrix, the aggregate size and shape, the difference in the strength and modulus of elasticity of the aggregate and cement matrix, and the link between these two components all have a role in the homogeneity of concrete. The geometrical qualities of the object also influence the scale effect. Due to significant differences in the stiffness of a concrete specimen and compression testing machine platens, in the area of their contact, the uniaxial stress state is disturbed by friction and pressure. As a result, specimens with a larger cross-sectional area show lower strength.

The fluctuating test results as shown in Figure 5 were presumably caused by two things. The first one, there were several load spreaders (Bearing strips) which were broken and partially cracked during the tensile strength test. Note that, in this study the thickness of load spreader is kept constant. The broken bearing-strips were strongly suspected to change the behavior of the biaxial stress on the concrete cylinder. Regarding this condition, how the thickness of the load spreader influence the behavior of tensile strength can be new topic of study. The second one, it was most likely caused by the unstable loading rate during the split tensile strength test. The loading rate was varied because the tool applied was simple equipment.

Typically, the wider the Bearing strip (indicated with higher t/r ratio) the higher the splitting tensile strength of the concrete. This found agree with former study done by Tang (1992). Simply it can be declared that when the load applied with wider spreader (higher t/r) it has tendency to be distributed load. Please note that t-r ratio is ratio of a half of contact width to the radius of cylinder, as illustrated in Fig. 1.

For all of the concrete specimens, the lowest tensile strength is obtained from cylinders with t/r=0 Cylinder with t/r=0 is the concrete without bearing strip. Meanwhile, the highest splitting tensile strength is obtained from specimen with h/d=1.
Based on this finding it is not recommended to do tensile test without applying bearing strip because of the lowest tensile strength gain.

Furthermore, in order to provide more objective findings of the experiment then comparison between compression and tensile test result can be addressed to Table 2.

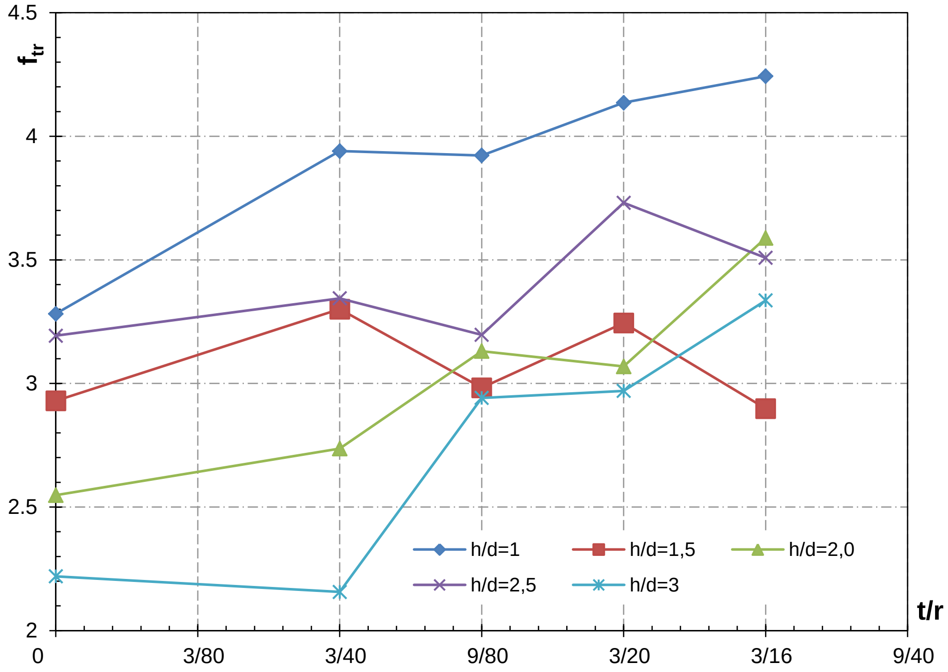

Figure 5. Typical relationship between splitting tensile strength and t/r ratio with various diameter of cylinders

Table 2. Detail of Concrete Specimen used in the study

Sample ID	dxh (mm)	h/d	t/r	Load Spreader		Number Of Specimens	Average Tensile Strength ft (MPa)	Average Compression Strength F'c (MPa)	Ftr/f'c (%)
				Width (mm)	Length (mm)				
T58-10-00	58x58	1.0	0	0	0	3	3.36	30.2	11.12
T58-15-00	58x87	1.5	0	0	0	3	3.41	30.2	11.29
T58-15-05	58x87	1.5	2/29	4	100	3	3.79	30.2	12.54
T58-15-10	58x87	1.5	3.5/29	7	100	3	3.76	30.2	12.45
T58-15-15	58x87	1.5	4.5/29	9	100	3	4.04	30.2	13.37
T58-15-20	58x87	1.5	5.5/29	11	100	3	3.30	30.2	10.92
T58-20-00	58x116	2.0	0	0	0	3	3.57	30.2	11.82
T58-20-05	58x116	2.0	2/29	4	150	3	3.53	30.2	11.68
T58-20-10	58x116	2.0	3.5/29	7	150	3	4.57	30.2	15.13
T58-20-15	58x116	2.0	4.5/29	9	150	3	4.54	30.2	15.03
T58-20-20	58x116	2.0	5.5/29	11	150	3	4.73	30.2	15.66
T58-25-00	58x145	2.5	0	0	0	3	3.96	30.2	13.11

Sample ID	dxh (mm)	h/d	t/r	Load Spreader		Number Of Specimens	Average Tensile Strength ft (MPa)	Average Compression Strength F'c (MPa)	Ftr/f'c (%)
				Width (mm)	Length (mm)				
T58-25-05	58x145	2.5	2/29	4	150	3	5.30	30.2	17.54
T58-25-10	58x145	2.5	3.5/29	7	150	3	3.71	30.2	12.28
T58-25-15	58x145	2.5	4.5/29	9	150	3	4.79	30.2	15.86
T58-30-00	58x145	3.0	0	0	0	3	3.17	30.2	10.49
T58-30-05	58x145	3.0	2/29	4	180	3	3.03	30.2	10.03
T58-30-10	58x145	3.0	3.5/29	7	180	3	3.83	30.2	12.68
T58-30-15	58x145	3.0	4.5/29	9	180	3	4.23	30.2	14.00
T58-30-20	58x145	3.0	5.5/29	11	180	3	4.76	30.2	15.76
T85-10-00	85x85	1.0	0	0	0	3	2.91	32.6	8.92
T85-10-05	85x85	1.0	3/42.5	6	100	3	3.25	32.6	9.96
T85-10-10	85x85	1.0	5/42.5	10	100	3	3.17	32.6	9.72
T85-10-15	85x85	1.0	6.5/42.5	13	100	3	3.58	32.6	10.98
T85-10-20	85x85	1.0	8/42.5	16	100	3	3.53	32.6	10.82
T85-15-00	85x127.5	1.5	0	0	0	3	2.62	32.6	8.03
T85-15-05	85x127.5	1.5	3/42.5	6	150	3	3.31	32.6	10.15
T85-15-10	85x127.5	1.5	5/42.5	10	150	3	3.22	32.6	9.87
T85-15-15	85x127.5	1.5	6.5/42.5	13	150	3	3.62	32.6	11.10
T85-15-20	85x127.5	1.5	8/42.5	16	150	3	3.59	32.6	11.01
T85-20-00	85x170	2.0	0	0	0	3	2.50	32.6	7.66
T85-20-05	85x170	2.0	3/42.5	6	180	3	2.89	32.6	8.86
T85-20-10	85x170	2.0	5/42.5	10	180	3	3.16	32.6	9.69
T85-20-15	85x170	2.0	6.5/42.5	13	180	3	3.29	32.6	10.09
T85-20-20	85x170	2.0	8/42.5	16	180	3	3.57	32.6	10.95
T85-25-00	85x213	2.5	0	0	0	3	3.00	32.6	9.20
T85-25-05	85x213	2.5	3/42.5	6	220	3	2.14	32.6	6.56
T85-25-10	85x213	2.5	5/42.5	10	220	3	3.36	32.6	10.30
T85-25-15	85x213	2.5	6.5/42.5	13	220	3	3.40	32.6	10.42
T85-25-20	85x213	2.5	8/42.5	16	220	3	3.48	32.6	10.67
T85-30-00	85x255	3.0	0	0	0	3	1.27	32.6	3.89
T85-30-05	85x255	3.0	3/42.5	6	270	3	1.23	32.6	3.77
T85-30-10	85x255	3.0	5/42.5	10	270	3	2.06	32.6	6.31
T85-30-15	85x255	3.0	6.5/42.5	13	270	3	1.71	32.6	5.24
T85-30-20	85x255	3.0	8/42.5	16	270	3	1.91	32.6	5.85
T109-10-00	109x109	1.0	0	0	0	3	3.58	35.12	10.19
T109-10-05	109x109	1.0	4/54.5	8	120	3	4.64	35.12	13.21
T109-10-10	109x109	1.0	6/54.5	12	120	3	4.67	35.12	13.29
T109-10-15	109x109	1.0	8/54.5	16	120	3	4.69	35.12	13.35
T109-10-20	109x109	1.0	10/54.5	20	120	3	4.96	35.12	14.12
T109-15-00	109x164	1.5	0	0	0	3	2.76	35.12	7.85
T109-15-05	109x164	1.5	4/54.5	8	180	3	2.80	35.12	7.97
T109-15-10	109x164	1.5	6/54.5	12	180	3	1.97	35.12	5.60
T109-15-15	109x164	1.5	8/54.5	16	180	3	2.07	35.12	5.89
T109-15-20	109x164	1.5	10/54.5	20	180	3	2.50	35.12	7.11
T109-20-00	109x218	2.0	0	0	0	3	2.08	35.12	5.92
T109-20-05	109x218	2.0	4/54.5	8	230	3	2.41	35.12	6.86
T109-20-10	109x218	2.0	6/54.5	12	230	3	2.71	35.12	7.71
T109-20-15	109x218	2.0	8/54.5	16	230	3	2.28	35.12	6.49
T109-20-20	109x218	2.0	10/54.5	20	230	3	2.77	35.12	7.88
T109-25-00	109x272.5	2.5	0	0	0	3	2.62	35.12	7.46
T109-25-05	109x272.5	2.5	4/54.5	8	300	3	2.60	35.12	7.40
T109-25-10	109x272.5	2.5	6/54.5	12	300	3	2.52	35.12	7.17
T109-25-15	109x272.5	2.5	8/54.5	16	300	3	3.00	35.12	8.54
T109-25-20	109x272.5	2.5	10/54.5	20	300	3	3.54	35.12	10.07
T109-30-00	109x327	3.0	0	0	0	3	2.26	35.12	6.43

Sample ID	dxh (mm)	h/d	t/r	Load Spreader		Number Of Specimens	Average Tensile Strength ft (MPa)	Average Compression Strength F'c (MPa)	Ftr/f'c (%)
				Width (mm)	Length (mm)				
T109-30-05	109x327	3.0	4/54.5	8	350	3	2.79	35.12	7.94
T109-30-10	109x327	3.0	6/54.5	12	350	3	2.501	35.12	7.12
T109-30-15	109x327	3.0	8/54.5	16	350	3	2.89	35.12	8.22
T109-30-20	109x327	3.0	10/54.5	20	350	3	2.92	35.12	8.31
T150-20-00	150x300	2.0	0	0	0	3	2.63	33.21	7.91
T150-20-05	150x300	2.0	5.5/75	11	350	3	2.62	33.21	7.88
T150-20-10	150x300	2.0	8.5/75	17	350	3	2.93	33.21	8.82
T150-20-20	150x300	2.0	14/75	28	350	3	3.58	33.21	10.77
T100-20-00	100x200	2.0	0	0	0	3	1.96	33.21	5.90
T100-20-05	100x200	2.0	4/50	8	210	3	2.12	33.21	6.38
T100-20-10	100x200	2.0	5.5/50	11	210	3	2.28	33.21	6.86
T100-20-15	100x200	2.0	7.5/50	15	210	3	2.39	33.21	7.19
T100-20-20	100x200	2.0	9.5/50	19	210	3	3.29	33.21	9.90

CONCLUSION

Based on data observed, here are some conclusions that can be drawn:

1. Typically, the wider the bearing strip as indicated with higher t/r ratio, the higher the splitting tensile strength of the concrete.
2. The load applied with wide Bearing strip has a tendency to be distributed one and the Splitting tensile strength rises nonlinearly as the t-r ratio increases. The highest splitting tensile strength is obtained from specimen with h/d=1
3. The splitting tensile strength decrease nonlinearly as the h/d increase.
4. it is not recommended to perform tensile test without applying bearing strip because of low tensile strength gaining

It is greatly recommended that this current study to be enhanced by using finite element analysis so the behavior of splitting tensile strength of normal concrete can be disclosed completely. In addition, the effect of the thickness of the bearing strip on the behavior of tensile strength can be new topic of study.

REFERENCES

ASTM C39-93a *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens* (Annual Book of ASTM Standard Vol. 04.02)

ASTM C78-90 *Standard Test Method for Flexural Strength of Cylindrical Concrete Specimens (Using Simple Beam with Third Point Loading)* (Annual Book of ASTM Standard Vol. 04.02)

ASTM C192-90 *Practice for Making and Curing Concrete Test Specimens in Laboratory* (Annual Book of ASTM Standard Vol. 04.02) (Annual Book of ASTM Standard Vol. 04.02)

ASTM C496-11 *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens* (Annual Book of ASTM Standard Vol. 04.02) (Annual Book of ASTM Standard Vol. 04.02)

Alca, N., Alexander, S.D.B., Macgregor, J.G., (1997), Effect of Size on Flexural Behavior of High-Strength Concrete Beams, *ACI Structural Journal, Vol. 94, No. 1, Pp. 59-67*

Bazant, Z.P., Planas, J.,(1998). Fracture and Size Effect in Concrete and Other Quasibrittle Materials, *CRC Press LLc*

Bažant, Z.P., Pang, S.D., Vorechovsky, M., Novák, D. and Pukl, R. (2004). Statistical size effect in quasibrittle materials: Computation and extreme value theory, Fracture Mechanics of Concrete Structures (Proc., FraMCoS-5, 5th Int. Conf. on Fracture Mech. of Concrete and Concr. Structures, Vail, Colo.), Vol. 1, V.C. Li, K.Y. Leung, Willam, K.J., and Billington, S.L., eds., IA-FraMCoS, 189-196. (*Available online on: http://cee.northwestern.edu/people/bazant/PDFs/Backup%20of%20Papers/P186.pdf*

Domagała, L. (2020), Size Effect in Compressive Strength Tests of Cored Specimens of Lightweight Aggregate Concrete, *Materials*, 13(1187),1-16 doi:10.3390/ma13051187, Available: https://www.mdpi.com/1996-1944/13/5/1187/pdf

Hamad, A.J. (2017). Size and shape effect of specimen on the compressive strength of HPLWFC reinforced with glass fibres, Journal of King Saud University – Engineering Sciences (2017) 29, 373–380 https://doi.org/10.1016/J.JKSUES.2015.09.003

Krauthammer, T., Elfahal M.M., Lim, J.H., Ohno, T., Beppu, M., and Markeset, G. (2003). Size Effect in High Strength Concrete Cylinders Subject to Axial Impact, International journal of Impact Engineering vol 28(9), pp. 1001-1016. http://dx.doi.org/10.1016/S0734-743X(02)00166-5

Kim J., Yi, S., Park, C., and Eo, S. (1999). Size Effect on Compressive Strength of Plain and Spirally Reinforced Concrete Cylinders, ACI Structural Journal, Vol. 96, Pp. 88-93

Mardani-Aghabaglou, A., Bayqra, S.H., Nobakhtjoo, A. (2021). Specimen size and shape effects on strength of concrete in the absence and presence of steel fibers, Revista de la construcción vol.20 no.1 Santiago abr. 2021, http://dx.doi.org/10.7764/rdlc.20.1.128

Merdana, INyoman. (2006), The Influence of Concrete Cylinder Size on Mechanical Properties of Semi Lightweight Pumice Concrete, Dosen Muda research report (Unpublished), Mataram

MacGregor, J.G. (1997). Reinforced Concrete Mechanics and Design, 3rd Edition, Prentice Hall International Inc., USA

Neville, A.M., Brooks, J.J. (1997) Concrete Technology, Addison Wesley Longman Limited, Singapore

Neville, A.M. (1996), A General Relation for Strength of Concrete Specimens of Different Shape and Size, *ACI Journal*, Proceedings Vol. 63, No. 10, Pp. 1095-1110

Tang, T., Shah, S.P., Ouyang,C. (1992). Fracture Mechanic and size Effect of Concrete in Tension, *Journal of Structural Engineering*, ASCE Vol 118, No 11, Pp.3169-3185, ISSN 0733-9445/92/0011-3169 Paper No. 2942

Wight, J.K. and MacGregor, J.G. (2012). Reinforced Concrete Mechanic and Design 6th Edition, Pearson Education, Inc., Upper Saddle River, New Jersey 07458

Zaitsev, Y.V., Kovler, K.L. (1986). Notch sensitivity of Concrete and Size Effect, Part II: Stress State Effect, *Cement and Concrete Research*, Vol.16 No. 1, *Pp. 7-16*