DOUBLE-PUNCH TEST FOR TENSILE STRENGTH OF CONCRETE

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The tensile strength of concrete is most commonly measured by the indirect split-cylinder test. Recently a new test, the double-punch test, has been proposed. The new test method had undergone preliminary experimental study to determine the testing procedure that would yield the most reliable and consistent results. However, further study was needed. By using the previously recommended procedure, the effect of several additional parameters on the tensile strength was studied. These parameters include the rate of stressing during the test and the effect of lightweight as well as regular concrete. The effects of the molds, machine lubricant, and testing machine are also being studied. Analysis of these results has led to a more thorough understanding and greater applicability of the new tensile test.

•THE tensile strength of concrete can be obtained from several different tests such as direct pull tests on briquettes, flexural tests on beams, ring tests, and splitting tests on cylinders (4). The most common is the indirect split-cylinder test (Brazilian test). In countries where the compressive strength is determined from cubes rather than from cylinders, tensile strengths have been obtained with a split-cube (Peltier Test) or a cube specimen tested diagonally. However, there are drawbacks connected to each of these tensile tests. Recently a new alternative test for concrete, the double-punch test, was developed (1). Preliminary work resulted in the determination of a standard procedure for the test (2). The purpose of the work was to further investigate experimentally the results of several varying parameters, including the rate of stressing during the test and the effect of lightweight as well as regular concrete. Whether the new test accurately reflected changes in molds, machine lubricant, and testing machine was also observed. This study has led to a more thorough understanding and greater applicability of the test. The ultimate goal in this study is to prepare this test for acceptance as a specification of ASTM.

TEST PROCEDURE

The double-punch test consists of a 6- by 6-in. (15.3 by 15.3 cm) concrete cylinder placed vertically between the loading platens of the testing machine and compressed by two 1.5-in. (3.8 cm) diameter steel punches 1 in. (2.54 cm) thick placed concentrically on the top and bottom surfaces of the cylinder (Fig. 1). No plywood bearing disks between the punch and specimen surface are needed provided the surfaces of the specimen are relatively smooth (2). The sample splits across many vertical diametral planes similar to the split-cylinder test (Fig. 2), but the double-punch technique requires much simpler testing.

The tensile strengths arrived at by this method show a good correlation with the split-cylinder method. The coefficients of variation, when compared, are similar or much lower as in the case of lightweight concrete.

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Figure 1. Apparatus for double-punch test.

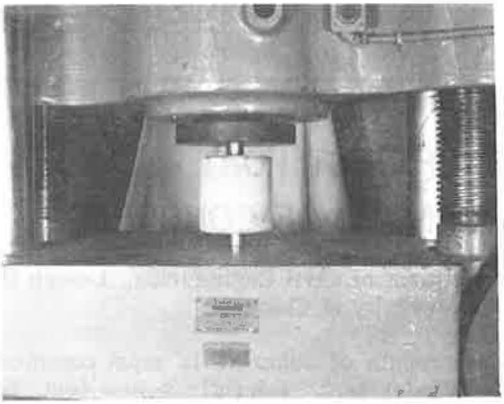


Figure 2. Double-punch failure mode.

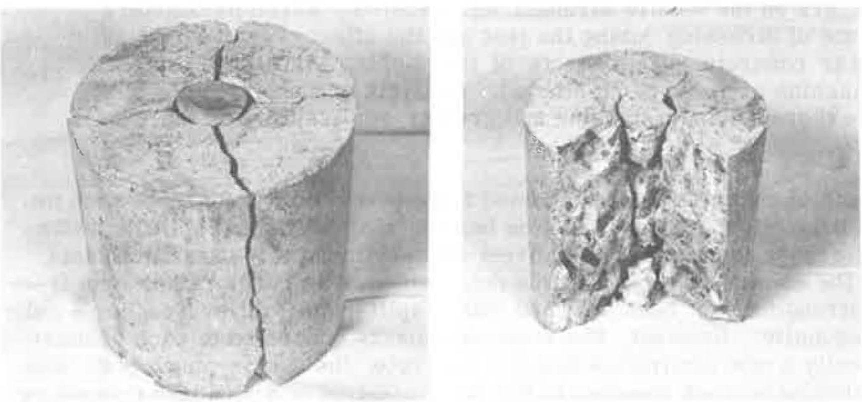


Figure 3. Improper failure mode in double-punch test due to very rough or unparallel top and bottom surfaces.

Table 1. Mix proportions (lb/yd^3) of concretes.

Mix	Water/ Cement Ratio	Water	Cement	Aggregate Fine	Aggregate Coarse	Darex (oz)
1	0.40	340	850	1,080	1,680	–
2	0.50	340	680	1,220	1,680	–
3	0.60	340	565	1,320	1,680	–
4	0.70	340	485	1,390	1,680	–
5	0.60	285	480	1,350	955	5½
6	0.44	292	658	910	955	5½
7	0.53	292	550	996	955	5½

Note: 1 lb/yd^3 = 0.593 276 kg/m^3.

STRESS DISTRIBUTION

Compressive loading transferred to the specimen through the steel punches produces a stress distribution that has been shown (1) to give an average tensile strength over all of the cracked diametral planes represented by the following formula:

$$f'_t = \frac{Q}{\pi(1.20\ bH - a^2)}$$

where

f'_t = tensile stress,
Q = applied load,
b = radius of cylinder,
H = height of cylinder, and
a = radius of punch.

This relationship is valid for $b/a \leq 5$ or $H/2a \leq 5$. For any ratio $b/a > 5$ or $H/2a > 5$, the limiting value $b = 5a$ or $H = 10a$ should be used.

MODE OF FAILURE

The ideal failure mode for the double-punch test is for the specimen to fail in many radial cracks. Inasmuch as the strength is an average value, the greater the number of radial cracks is, the more accurate the value of strength will be. Many cracks also indicate more even stress distribution in the test specimen. Where the specimen's top and bottom surfaces are very rough or not parallel to each other, the specimen may fail in only two cracks and usually at a significantly lower load (Fig. 3). Most specimens fail in three or four cracks.

EXPERIMENTAL DETAILS

Materials

Throughout the experiment, two types of coarse aggregate were used: a ¾-in. (1.9 cm) maximum size crushed stone for all regular concrete specimens, and a ¾-in. (1.9 cm) maximum size expanded shale (Nytralite) for all lightweight concrete specimens. The same sand, fineness modulus 2.95, and ordinary Type I portland cement were used in all cases. Darex was used as an air-entraining agent for the lightweight batches.

Test Apparatus

The loading punches were made from No. 1018 cold rolled steel and were 1.5 in. (3.8 cm) in diameter and 1 in. (2.54 cm) thick. All surfaces were machined and the ends parallel. Two plywood disks, 6 in. (15.3 cm) in diameter with a 1.5-in. (3.8 cm) diameter hole in the center, were used as templates to center the punches on the concrete specimen and then between the loading platens of the machine. A 300-kip (1334 kN) Baldwin hydraulic machine was used for all compression, split-cylinder, and double-punch tests except where noted otherwise. In those cases either a 120-kip (534 kN) Tinius-Olsen mechanical machine or a 60-kip (267 kN) Baldwin hydraulic machine was used.

Mix Design

Mix proportions for the various mixes of concrete used in this work are given in Table 1. Each batch was mixed in a rotary mixer, and specimens were cast in accordance with ASTM C 192.

Cylinders used for double-punch testing have a diameter and height of 6 in. (15.3 cm). The cylinders, unless specified otherwise, were cast in wax-coated, disposable cardboard molds, meeting the requirements of ASTM C 470. These molds were cut to 6 in. (15.3 cm) in height for double-punch specimens. Cube specimens were 6 in. (15.3 cm) on edge and cast in either plywood or steel molds.

Immediately after casting, the samples were covered with plastic sheets for 24 hour hours. The molds were then stripped from the sample, and the samples were placed in a moist curing room (ASTM C 511) for the remaining 27 days. Lightweight specimens were removed from the moist curing room after 7 days and covered with wet burlap and plastic for the remaining 21 days. Standard control specimens were cast for each mixture.

RESULTS

Control Tests

Control tests were made for each mix and the values are given in Table 2. The double-punch test gave more consistent results in many cases as shown by the lower coefficients of variation (Table 2).

In Figure 4 the double-punch strengths closely parallel the strengths given by split-cylinder tests in the regular concrete (mixes 1-4). However, the relationship was not quite so good in the lightweight concrete (mixes 5-7).

In the split-cylinder test, the plane of failure of the specimen is predetermined. That is, it will crack vertically whether that plane is the strongest or weakest area of the specimen. In contrast to this, the double-punch test does not predetermine the failure plane, and therefore the specimen will fail in the weakest planes. This explains the consistently lower strengths obtained.

Effect of Molds

The purposes of this experiment were to investigate any effects on double-punch test strengths caused by different types of molds and to see whether these effects, if any, are comparable to those reflected in split-cylinder testing.

In split-cylinder testing, cylinders cast in cardboard molds give specimens with lower strengths and higher variability than specimens cast in steel molds (3).

Regular and lightweight concrete specimens were cast in both cardboard and steel cylinder molds. Standard 12-in. (30.5 cm) cardboard molds were cut to 6-in. (15.3 cm) heights, and false bottoms were made for the steel molds. Cube specimens were also cast in both plywood and steel molds.

Table 3 gives test results that show the double-punch test consistently reflects greater strengths and lower coefficients of variation in the case of steel molds. This therefore indicates the sensitivity of the double-punch method in recording these changes.

Effect of Stressing Rate

The influence of the stressing rate was measured by testing mixes 3 and 5 each at 7 and 28 days. Regular concrete (mix 3) showed a gradual decrease in strength with an increased rate (Fig. 5). Lightweight concrete (mix 5) was found to be more sensitive to the rate. Beyond 200 psi/min (1.38 MPa/min), the strength rose steeply to around 500 psi/min (3.45 MPa/min), then fell off. The 28-day strengths are also given in Table 4.

Effect of Testing Machine

Testing machine conditions may significantly affect the measured strength of concrete. Care must be taken to accurately align the punches and specimen in the testing machine. Each machine used was fitted with a spherical bearing block on the upper platen. Tests were made on the type of lubricant used on the upper platen. With a poor lubricant, the platen can move initially but breaks down under load and becomes effectively fixed. With a high-pressure lubricant, the spherical bearing block can adjust throughout the loading.

In this test a low-grade, all-purpose grease was compared to a high-pressure graphite lubricant. As with the mold test, the double-punch test was sensitive to this condition and was able to accurately reflect the changes. In the high-pressure graphite lubricant [361 psi (2.49 MPa)], the strength was significantly higher because of the more

Table 2. Results of control specimens.

Mix	Water/ Cement Ratio	Simple Compression[a], f_c' (psi)	Split Cylinder[b], f_t' (psi)	Coefficient of Variation, Split-Cylinder (percent)	Double-Punch[c] f_t' (psi)	Coefficient of Variation, Double-Punch (percent)
1	0.40	5,396	505	2.16	376	4.89
2	0.50	4,907	506	3.17	394	6.96
3	0.60	4,176	461	9.76	373	1.79
4	0.70	3,634	398	9.68	354	3.76
5	0.60	3,749	374	7.38	261	2.18
6	0.44	4,100	427	9.63	331	6.40
7	0.53	4,556	440	6.04	321	3.20

Note: 1 psi = 0.006 894 757 MPa.

[a]Average of three tests.

[b]Average of three tests, mixes 1 to 4; eight tests, mixes 5 to 7.

[c]Average of three tests, mixes 1 to 4; five tests, mixes 5 to 7.

Figure 4. Relationship of double-punch to split-cylinder strengths in various mixes used.

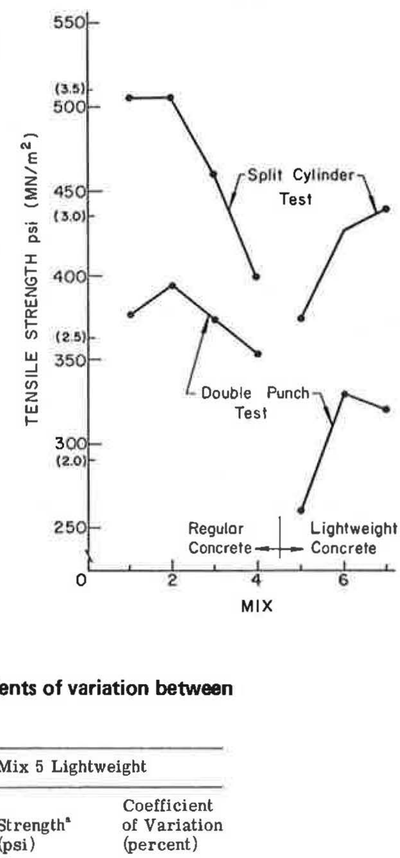


Table 3. Differences in strengths and coefficients of variation between cardboard and steel molds.

Mold Type	Mix 4 Regular Strength[a] (psi)	Mix 4 Regular Coefficient of Variation (percent)	Mix 5 Lightweight Strength[a] (psi)	Mix 5 Lightweight Coefficient of Variation (percent)
Cylinder				
Cardboard	333	5.98	261	2.18
Steel	364	2.07	264	2.64
Cube				
Plywood	335	1.53	271	2.99
Steel	354	1.32	274	1.78

Note: 1 psi = 0.006 894 757 MPa.

[a]Average of four tests.

Table 4. Effect of stressing rate.

Rate (psi/min)	Mix 3 Strength[a] (psi)	Mix 3 Coefficient of Variation (percent)	Mix 5 Strength[a] (psi)	Mix 5 Coefficient of Variation (percent)
100	379	2.74	264	1.59
200	390	4.14	261	2.18
300	364	7.23	276	6.46
500	368	4.18	287	4.75
1,000	362	14.00	267	3.72

Note: 1 psi/min = 0.006 894 757 MPa/min.

[a]Average of 6 test results at 28 days.

Table 5. Effect of size of testing machine.

Machine Strength (kip)	Mix 4 Strength (psi)	Coefficient of Variation (percent)
60[a]	361	1.49
120[a]	362	1.61
300[b]	358	3.10

Note: 1 psi = 0.006 894 757 MPa.

[a]Average of three tests.

[b]Average of six tests.

Figure 5. Results of 28-day tensile strength versus rate of loading.

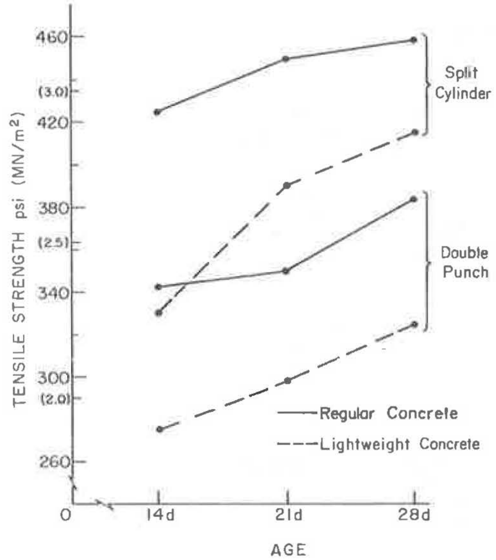
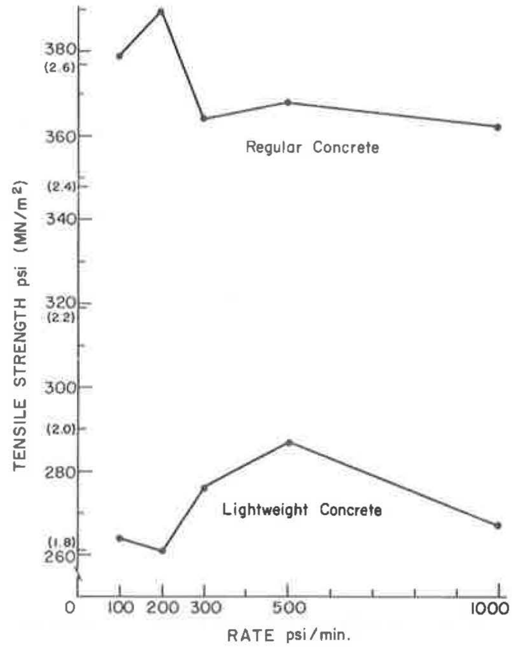


Figure 6. Comparison of split-cylinder and double-punch test throughout curing.



evenly distributed load, and the coefficient of variation was much lower (1.69 percent) than with the poor lubricant [strength 329 psi (2.27 MPa); coefficient of variation 11.3 percent]. (The strength data are an average of three test results.)

The possible effect of the size of testing machine was also investigated. The results are given in Table 5. Three machines, a 300-kip (1334 kN) Baldwin hydraulic machine, a 120-kip (534 kN) Tinius-Olsen mechanical machine, and a 60-kip (267 kN) Baldwin hydraulic machine were used for this test. The measured double-punch tensile strength of concrete is seen to be insensitive to the size of testing machine.

Curing Rate

This test determined if specimens tested by the double-punch method reflected the same strength changes throughout their curing period as those tested by the split-cylinder method. Both regular (mix 2) and lightweight (mix 5) concretes were studied. Figure 6 shows the parallel correlation between the two tests for both types of concrete. This therefore indicates the sensitivity of both methods for recording strength changes with time.

DOUBLE-PUNCH TEST ADVANTAGES

There are four primary advantages of the double-punch test over the split-cylinder test.

1. The double-punch test gives an average tensile strength that exists over all of the failure planes and gives a "truer" strength than does the split-cylinder test because of the weak link theory.
2. Because the ultimate load needed for failure is much lower [20 to 30 kips (89 to 133 kN) compared to 40 to 60 kips (178 to 267 kN)], a smaller machine can be used. This makes the test more attractive for field tests with portable machines.
3. For those countries that use cubes for compression tests, the double-punch method is much easier than the diagonal split-cube procedure.

CONCLUSIONS

1. Control tests—The strengths of concrete obtained by the double-punch test are generally more consistent than those obtained by the split-cylinder test method.
2. Molds—The double-punch procedure shows that use of steel molds for casting specimens gives higher strengths with lower variability than use of cardboard molds; therefore it is sensitive to the type of mold used.
3. Stressing rate—Increasing the stressing rate for the double-punch test gives lower strengths for regular concrete and higher strengths for lightweight concrete.
4. Testing machine—The double-punch tensile strength of concrete test specimens is independent of the size of testing machine. However, the type of lubricant used on the upper platen does affect the measured strength. A good (high-pressure) lubricant results in higher and less variable tensile strengths.
5. Curing rate—The double-punch test and the split-cylinder test reflect comparable increases in tensile strength throughout the curing period of test specimens.

In order to standardize test procedure and make results reproducible from laboratory to laboratory it is recommended, based on past (2) and present studies, that

1. Concrete cylinders 6 by 6 in. (15.3 by 15.3 cm) be used;
2. Steel punches 1.5 in. (3.8 cm) in diameter and 1 in. (2.54 cm) thick be used;
3. No plywood bearing disks are needed;
4. A stressing rate of 100 to 200 psi/min (0.69 to 1.38 MPa/min) be used; and
5. A high-pressure lubricant on the spherical bearing block for lower testing variability during the double-punch test be used.

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