Journal of Critical Reviews

ISSN- 2394-5125 Vol 7, Issue 4, 2020

Review Article

COMPARING THE RESULTS OBTAINED FROM IN-SITU METHODS FOR DETERMINING THE STRENGTH OF THE CEMENT MORTARS

[1]ALI SABERI VARZANEH; [2]MAHMOUD NADERI

[1] PhD student, civil engineering, technical and engineering department, International Imam Khomeini (may Allah consecrate the honorable soil of his tomb), Qazvin Branch, Qazvin, Iran;
[2]Professor, technical and engineering department, International Imam Khomeini (may Allah consecrate the honorable soil of his tomb), Qazvin Branch, Qazvin, Iran;

Received: 05.12.2019 Revised: 10.01.2020 Accepted: 16.02.2020

Abstract
Nowadays, the in-situ evaluation of the cement masonry strength is inevitable. The in-situ methods of determining the strength are usually applied for evaluating the status quo and identification of the reason(s) of the masonry and materials' failure. This article makes use of two in-situ methods, namely twist-off and friction-transfer, as well as standard laboratory methods to evaluate the mechanical properties of cement mortars, including compressive, flexural and tensile strength, in different ages and under various curing methods. Considering the differences in the performance of the above-mentioned in-situ methods, the results obtained from the two methods will be compared so that their differences can be figured out. Moreover, the correlation between the results obtained from the in-situ methods and the laboratory methods has been made clear and calibration curves have been offered for use in determining the mechanical properties of the mortars. The obtained results are expressive of a difference by about 30% between the readings obtained in in-situ twist-off and friction-transfer methods. Furthermore, there is a linear correlation found with a high intensity of 90% between the standard laboratory methods and the aforesaid in-situ methods.

Keywords: cement masonry, mechanical properties, twist-off, friction-transfer, calibration curve

 DOI: http://dx.doi.org/10.31838/jcr.07.04.102

INTRODUCTION

Cement masonry strength test might be possibly needed on the work site for various reasons such as the standard samples' properties inconsistency with the technical properties, dubiousness of the implementation method such as condensation and curing, use change, damage and so forth. The in-situ cement masonry strength determinations are divided into three sets of invasive, semi-invasive and non-invasive. The non-invasive method does not directly measure the materials' strength rather some characteristics related to strength are measured and, subsequently, the strength is estimated based on the relation obtained between the properties and the strength. Invasive experiments, as well, have certain limitations for they inter alia cause the destruction of the test segment and they may cause the shutdown of the structure's exploitation during the experiment, they are costly and it is not possible to access all spots of the structure for performing the invasive test. In general, the choice of the test method depends on certain conditions like evaluation reason, test site selection, the information the method is going to give us, number of needed experiments, enforceability and the experiments' costs.

Amongst the non-invasive tests, Schmidt's hammer test [1] can be pointed out. This test measures the rebound of a given mass after being hit on the materials' surface. Of course, the obtained numbers are influenced by the existence of cavity or crack inside or on the surface of the constructional materials hence the obtained results are likely to fall short of showing the real quality of the materials. The other non-invasive experiment is the ultrasound pulse velocity test [2]. This method includes the measurement of the velocities of the pulses sent from one side and received on the other. To test concrete and mortar, pulse-generators with frequencies in a range from 25KHz to 100KHz are permissible. Amongst the invasive methods, coring [3] can be pointed out. This method includes extraction of a cylindrical sample from the test site which is done by the use of a special coring device. Of course, in this method, fine cracks develop in the sample during coring and this may influence the results; thus, the results obtained from this method usually give a compressive strength below the real one [4]. The other invasive method is the pullout strength of hardened concrete [5]. In this method, a metal segment is buried inside concrete or mortar and it is pulled out through the exertion of tensile force from inside thereof.

Amongst the semi-invasive tests, the "direct pull-off" can be pointed out [6]. In this method, a steel cylinder is stuck to the test site's surface and it is subsequently pulled out of the concrete surface through the exertion of tensile force. Amongst the other semi-invasive in-situ tests, "twist-off" [7] and "friction-transfer" [8] can be pointed out. In twist-off, a steel cylinder is seminally stuck in the surface of the test site using epoxy resin/glue and it is subsequently subjected to torsional moment using an ordinary crack-meter till it is separated from the surface of the concrete or mortar. In the "friction-transfer" test, use is seminally made of core drill to pull out a small core on the test site. Then, the metal test device is fixed on the core and subjects it to a torsional moment until it undergoes failure. As was mentioned, there are differences in performing twist-off and friction-transfer tests with the most important of them being the creation of core in the friction-transfer test. Twist-off and friction-transfer methods are utilized for determining the strength of concrete, rocks, and adhesion between the reparatory mortar and concrete bed, as well [9-14]. The prior research on the comparison of the results obtained from the abovementioned tests and concrete's compressive strength is reflective of the high correlation coefficient between them.

Considering the unique efficiency of twist-off and friction-transfer tests rendering them applicable under any laboratory and environmental conditions, these tests can be employed for determining the in-vitro and in-situ determination of the strength rates of the constructional materials consumed in the road and building and structure industry to control the quality and perform research. Considering the very superficial and trivial amount of damage imposed in twist-off and friction-transfer tests, these tests fall in the category of semi-invasive tests or, in more precise terms, in the group of tests with least damage. Since failure occurs in these tests in the intended object, their results are more credible in comparison to the degree one hardness determination tests or the tests that indirectly determine the masonry strength. Since it is necessary for the acceptance of every new test to compare the obtained results with the corresponding results obtained from the common standard tests, the present article intends to do this comparison and come up with the relations between the strength values attained from carrying out friction-transfer and twist-off tests and the standard compressive, tensile and flexural experiments on the cement mortars.

LABORATORY WORKS

Used Constructional Materials

The cement used for producing the mortars is of type two featuring a density of 3007kg/m^3. Sand and gravel have been used with the maximum amounts of 4.75mm and 19mm, respectively; the grading of the sand and gravel has been conducted according to ASTM C136 Standard [15]. The water absorption rates of the gravel and sand were measured equal to 2.6% and 3.2% respectively based on ASTM C128 [16] and ASTM C127 [17] Standards. The densities of sand and gravel, as well, are correspondingly equal to 2330kg/m3 and 2510kg/m3 in a saturation state with a dry surface. Figure (1) illustrates the grading diagram of sand.

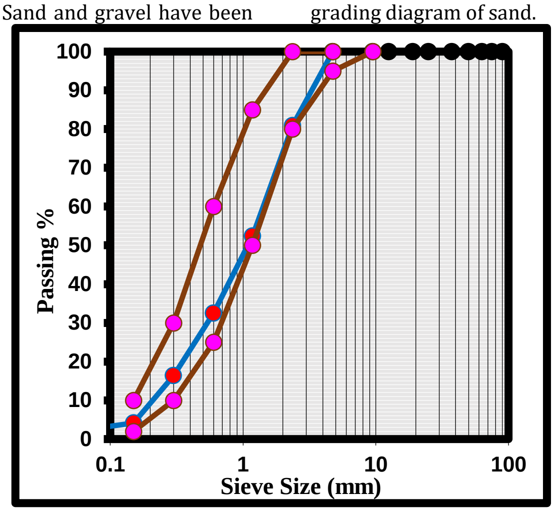


Figure (1): sand grading diagram

The bi-component glue used herein is of epoxy resin type featuring a volumetric composition of one to one, a shear strength rate of 15MPa, a seven-day compressive strength rate of 70MPa and an elasticity module of 12750MPa. The curing materials were also of polyolefin type.

Reparatory Mortar:

To produce the cement mortars, use was made of two aggregation plans with 1:2 cement to sand ratio. The water to cement ratio was 0.5 in one of the mortars and 0.4 in another. After production, the experimental samples were subjected to "soaking", "curing materials" and "left in open space". Then, the required tests were carried out on them in 3-, 7-, 28-, 42- and 90-day ages.

Laboratory Methods:

Twist-Off Method:

In the twist-off test, a metal cylinder, 50mm in diameter, was stuck onto the test site. Then, as shown in figure (2), use was made of an ordinary twist-meter device following subjecting the metal cylinder to a torsional moment until the object underwent failure.

Figure (2): in-situ twist-off test

In the twist-off test, the torsional moment, T, is continuously increased until the object undergoes failure and the relation between the shear stress and torsional moment can be calculated as shown in the relation (1) beneath:

$$\tau = \frac{Tr}{J} = \frac{2T}{\pi r^3} \quad (1)$$

Where J is the surface's second polar moment and r is the core diameter.

Friction-Transfer Test:

To determine the strength of the cement mortars using this test, a coring device was first utilized to create a partial core, 25mm in height, in the mortar; then, the friction-transfer test device was installed thereon and the sample was subsequently subjected to torsional moment using an ordinary torsion-meter device until the partial core underwent failure (figure 3).

Figure (3): performing the friction-transfer test

Mortars' Mechanical Properties:

The compressive strength of the mortars was measured using ASTM C109 Standard [18]. For every mortar type, there was a need for six standard cubic specimens, 20mm in dimensions. To determine the mortar's flexural strength, as well, ASTM C348 [19] was the standard of choice; the specimens were in prism form with 40×40×160mm dimensions. To determine the mortars' tensile strength, use was made of ASTM C190 Standard [20] and briquette specimens, 75mm in length, at most 40mm and at least 25mm in width and 25mm in thickness, were constructed. The compressive strength was measured on average based on three sub-tests (Figure 4).

(a) Compressive strength (b) Flexural strength (c) Tensile strength

Figure (4): determining the mechanical properties of the cement mortars

Results and Their Analysis:

Correlation between the Results Obtained from In-Situ Tests and Mortars' Mechanical Properties:

Table (1) summarizes the results obtained from the in-situ twist-off test and standard laboratory compressive, flexural and tensile strength experiments on M1 Mortar.

Table 1: the results of the twist-off test and compressive, flexural, tensile strength experiments on M1 mortars (mega-pascal)

Test method	3-day			7-day			28-day			42-day			90-day		
	Water	Curing materials	Open space	Water	Curing materials	Open space	Water	Curing materials	Open space	Water	Curing materials	Open space	Water	Curing materials	Open space
Twist-off	4.03	3.21	2.5	5.99	5.04	3.87	7.98	6.3	4.96	8.64	6.94	5.54	9.28	7.54	5.85
Friction-transfer	2.72	2.14	1.62	4.09	3.45	2.61	5.29	4.38	3.37	5.89	4.8	3.75	6.43	5.13	3.98
Compressive strength	28.5	23.4	16.1	40.6	36.1	24.8	56.2	48.6	33.7	61	50.4	36.2	64.7	53.1	37.6
Flexural strength	7.82	7.36	5.87	10.12	9.89	7.48	11.04	10.47	8.05	11.5	10.81	8.74	12.08	11.5	9.09
Tensile strength	2.35	1.9	1.14	3.45	2.92	1.83	4.64	3.79	2.28	4.87	3.97	2.45	5.44	4.37	2.79

It can be observed in Table (1) that curing causes an increase in the results obtained from the twist-off test as well as in the laboratory compressive, flexural and tensile strength experiments. The compressive strength of the 3-, 7-, 28-, 42- and 90-day samples has been increased by 1.77, 1.64, 1.67, 1.69 and 1.72 times, respectively, subject to soaking in water as compared to the samples left in open spaces. For the mortar subjected to curing materials, as well, the increase in compressive strength has been 1.45, 1.46, 1.44, 1.39 and 1.41 times, respectively, in comparison to the same abovementioned day-old specimens that were left in open space. This same ascending trend is seen in the tensile and flexural strength rates as well as in the results of the twist-off test. The increases in the tensile strength of the water-soaked specimens were 2.06, 1.89, 2.04, 1.99 and 1.95 times, respectively, in contrast to the tensile strength of the mortars left in the open space. The tensile strength rates of the mortar subjected to curing materials were also found increased by 1.67, 1.59, 1.66, 1.62 and 1.57 times, respectively. Also, in a comparison between the flexural strength rates of mortars soaked in water and the mortars left in open space, the flexural strength rates were found increased by 1.33, 1.35, 1.37, 1.31 and 1.33 times.

Table (2) presents the results obtained from the in-situ twist-off test and standard laboratory compressive, flexural and tensile strength experiments on M2 Mortar Specimen.

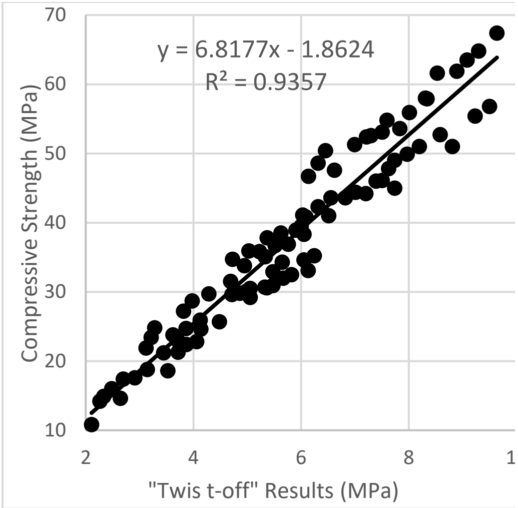
Table 2: Results of the twist-off test and compressive, flexural and tensile strength experiments on M2 Mortar Specimen (Mega-Pascal)

Test method	3-day			7-day			28-day			42-day			90-day		
	Water	Curing materials	Open space	Water	Curing materials	Open space	Water	Curing materials	Open space	Water	Curing materials	Open space	Water	Curing materials	Open space
Twist-off	4.03	3.21	2.5	5.99	5.04	3.87	7.98	6.3	4.96	8.64	6.94	5.54	9.28	7.54	5.85
Friction-transfer	2.36	1.89	1.44	3.61	3.05	2.31	4.69	3.84	2.97	5.19	4.2	3.35	5.64	4.56	3.55
Compressive strength	28.5	23.4	16.1	40.6	36.1	24.8	56.2	48.6	33.7	61	50.4	36.2	64.7	53.1	37.6
Flexural strength	7.82	7.36	5.87	10.12	9.89	7.48	11.04	10.47	8.05	11.5	10.81	8.74	12.08	11.5	9.09
Tensile strength	2.35	1.9	1.14	3.45	2.92	1.83	4.64	3.79	2.28	4.87	3.97	2.45	5.44	4.37	2.79

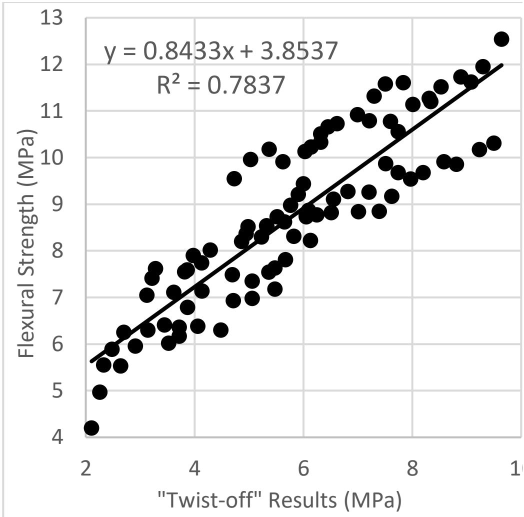
It can be observed in Table (2) that curing brings about an increase in the results of the twist-off test as well as in the laboratory compressive, flexural and tensile strength experiments. The compressive strength of the water-soaked 3-, 7-, 28-, 42- and 90-day samples has been increased by 1.77, 1.63, 1.66, 1.65 and 1.69 times the samples that were left in the open space. For mortar subjected to curing materials, as well, the increases in the compressive strength have been 1.45, 1.44, 1.43, 1.39 and 1.4 times the same abovementioned day-old samples that were left in the open space. This same ascending trend is also seen in the tensile and flexural strength as well as in the results of the twist-off test. The increases in the tensile strength of the water-soaked samples were 2.08, 1.89, 2, 1.92 and 1.96 times those of the mortars left in open space. The tensile strength increases of the mortars subjected to curing materials are 1.56, 1.55, 1.64, 1.58 and 1.56 times, respectively. Additionally, in a comparison of the flexural strength of the water-soaked mortars and the mortars left in open space, it was found out that the flexural strength has been increased by 1.37, 1.38, 1.34, 1.31 and 1.31 times, respectively.

Considering the results obtained from the compressive, flexural and tensile strength experiments on both of the aforementioned mortars, it can be observed that curing has a large deal of effect on their strength. Knowing that the cement's hydration only takes place in the capillary pores filled with water, efforts should be made in line with avoiding water decline as a result of evaporation so that the hydration can be completed perfectly and this is feasible through curing. In the prior research on the mortars' compressive strength, it was concluded that the 28-day compressive strength of the mortar is 37% higher than the 7-day compressive strength [21]. Moreover, the 28-day compressive strength was found 54% higher in another study for water-soaked mortars in contrast to 7-day compressive strength [22]. In this study, as well, the 28-day compressive strength of the water-soaked mortar was 40% higher than the compressive strength of the 7-day sample of the same mortar. It was made clear in a study of the mortars' flexural strength that the flexural strength of a 28-day sample is about 7% higher than the flexural strength of a 7-day sample [22]. In this study, as well, the flexural strength was found 7.5% higher in the 28-days sample as compared to the 7-day sample.

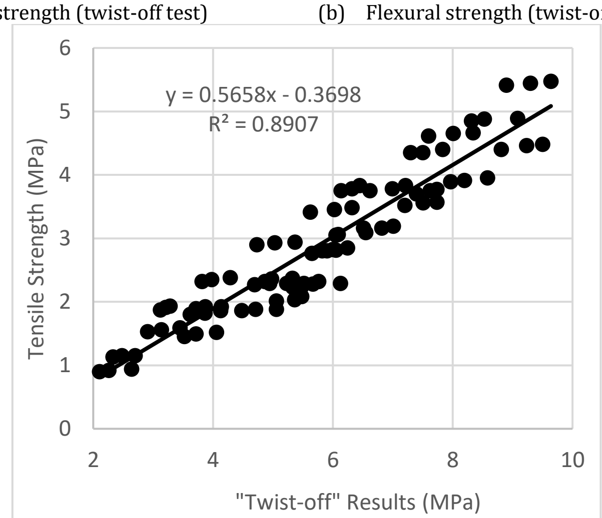
Figure (5) displays the correlation between the results obtained from the twist-off test and standard laboratory experiments on both of the mortar types.



(a) Compressive strength (twist-off test)



(b) Flexural strength (twist-off test)

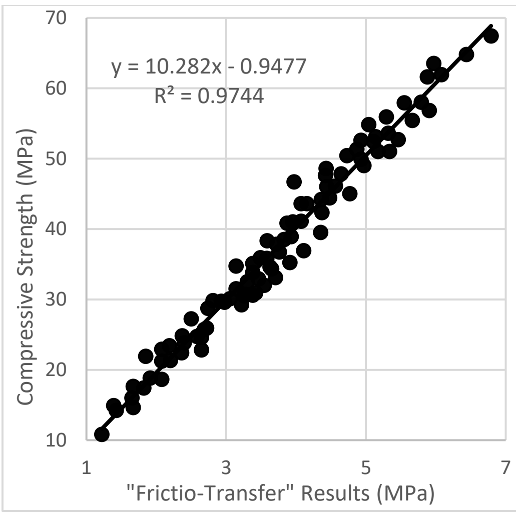


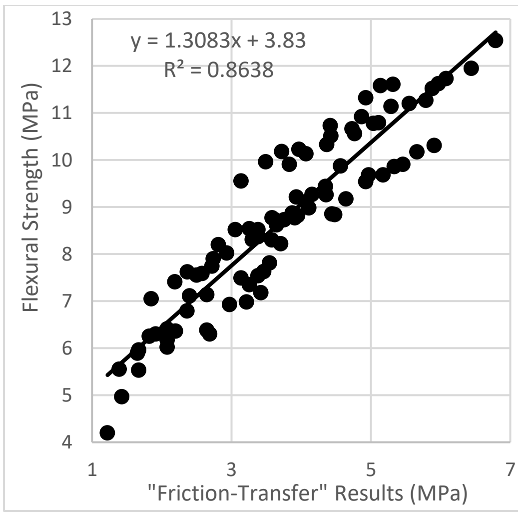
(c) Tensile strength (twist-off test)

Figure (5): correlation between the results of the twist-off test and mechanical properties of cement mortars

It can be seen in figure (5) that there is a high correlation between the results of compressive, flexural and tensile strength rates of the mortars with the results obtained from the twist-off test. The correlation between the obtained readings of the twist-off test and compressive strength is equal to 96.6%. Furthermore, the correlation coefficients between the mortars' flexural and tensile strength rates with the twist-off test results are 89% and 94.3%, respectively. It can be concluded based on the correlation coefficients obtained between the results of the twist-off test and results of standard laboratory experiments that the twist-off test can be used as an in-situ method with trivial destruction for determining the mechanical properties of the cement mortars.

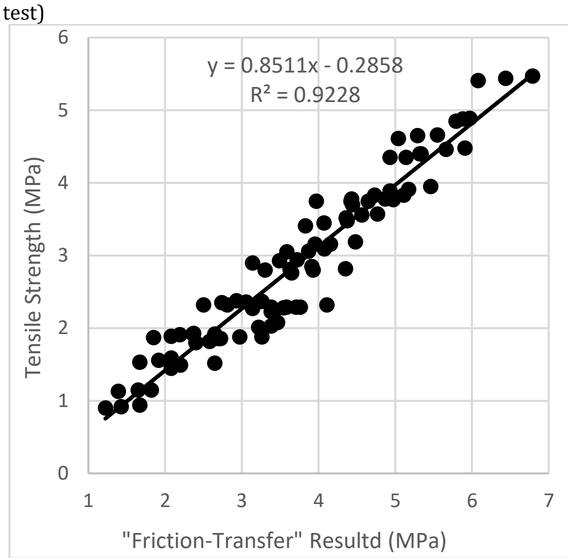
Figure (6) depicts the correlation between the results obtained from the friction-transfer test and standard laboratory experiments of both of the mortar types.





(a) Compressive strength (friction-transfer test)

(b) Flexural strength (friction-transfer test)



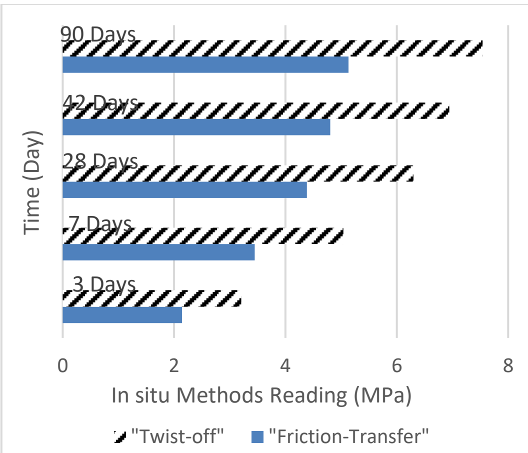
(c) Tensile strength (friction-transfer test)

Figure (6): correlation between the results of the friction-transfer test and mechanical properties of cement mortars

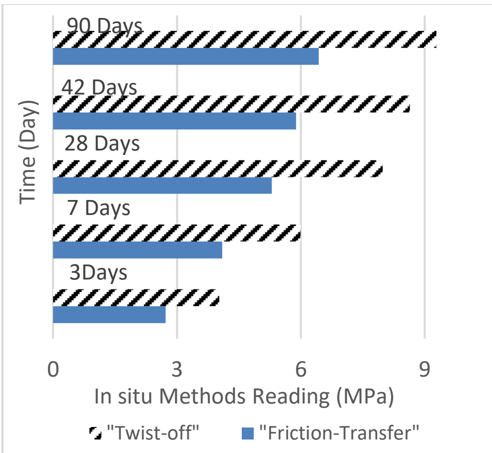
It can be observed in figure (6) that there is a high correlation between the results of mortars' compressive, flexural and tensile strength rates with the results obtained from the friction-transfer test. The correlation between the readings obtained from the friction-transfer test and the compressive strength experiment is 98%. Besides, the correlation coefficients between the flexural and tensile strength rates of the mortars with the twist-off test's results are 93% and 96%, respectively. It can be concluded based on the coefficients of correlation obtained between the results of the friction-transfer test and standard laboratory experiments that friction-transfer test can be utilized as an in-situ method with trivial destruction for determining the mechanical properties of cement mortars.

Comparison of the Results Obtained from Friction-Transfer and Twist-Off Tests:

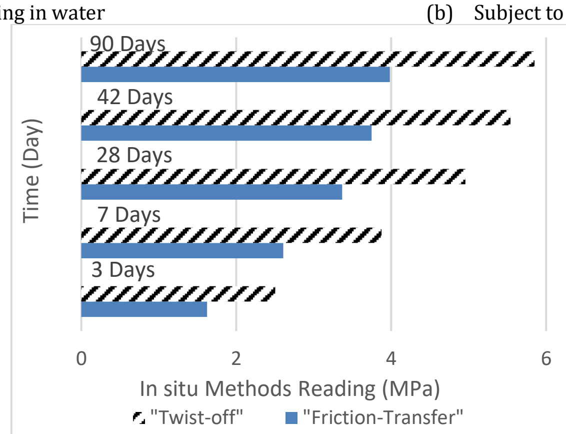
Figure (7) illustrates the results obtained from twist-off and friction-transfer tests on M1 type of cement mortars in various ages subject to different curing conditions.



(a) Soaking in water



(b) Subject to curing materials



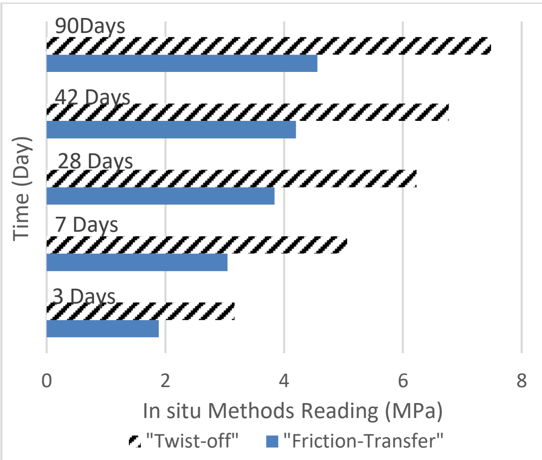
Left in open spaces

Figure (7): comparison of the results obtained in twist-off and friction-transfer tests on M1 Mortar

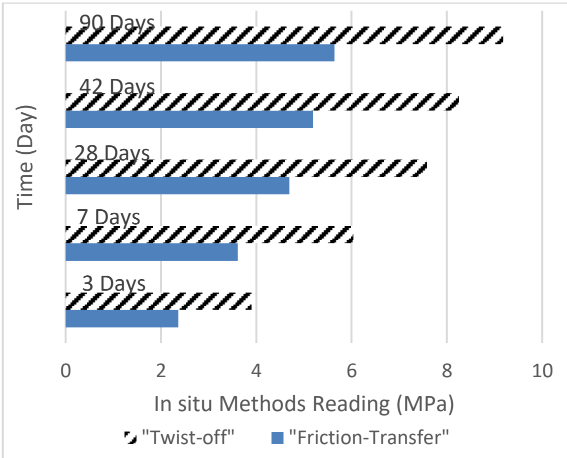
It is observed according to figure (7) that the readings obtained from the twist-off test are higher for all the samples in comparison to the results obtained from the friction-transfer test. Because coring is seminally carried out on the test site in the friction-transfer test, micro-cracks are developed inside the mortar and this causes drops in the results obtained from the friction-transfer test as compared to those attained in the twist-off test. The twist-off test is conducted without coring by direct attachment of the metal cylinder on the mortar surface; thus, before performing the test, no crack is created in the specimen and the obtained results appear higher than those attained in the friction-transfer test.

It can be understood based on Figure (7a) that the results obtained from the twist-off test are averagely 31.9% higher than the results obtained from the friction-transfer test for the water-soaked samples. It can be inferred from Figure (7b) that the results of the twist-off test are about 31.5% higher than those attained in the friction-transfer test for the samples subjected to curing materials. It is also observed according to Figure (7c) that the results of the twist-off test are 32.8% higher than those obtained from the friction-transfer test. It can be generally concluded that the amounts of the readings obtained for this mortar type in the twist-off test are about 32.1% higher than those obtained in the friction-transfer test.

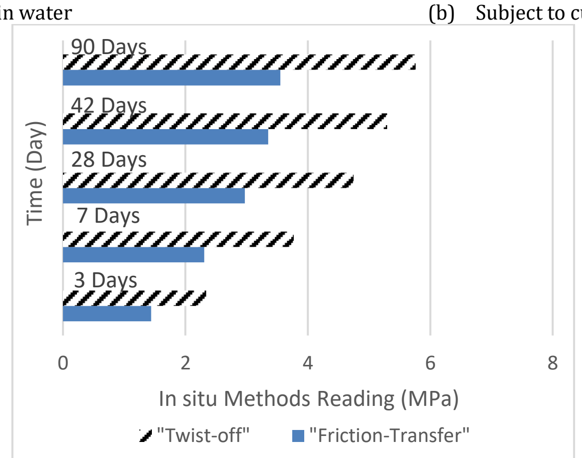
Figure (8) exhibits the results obtained from the twist-off and friction-transfer tests on M2 type of cement mortars in various ages and under different curing conditions.



(a) Soaking in water



(b) Subject to curing materials



Left in open spaces

Figure (8): comparison of the results obtained in twist-off and friction-transfer tests on M2 Mortar

It is observed in Figure (8a) that the amounts of the results obtained from the twist-off test are about 38.7% higher than those attained from the friction-transfer test, on average, for specimens soaked in water. It can be understood from Figure (8b) that the results obtained from the twist-off test are about 39.1% higher than those attained in the friction-transfer test for specimens subjected to curing materials. It can be discerned additionally according to Figure (8c) that the results obtained from the twist-off test are 37.9% higher than those obtained from the friction-transfer test. It can be generally concluded that the amounts of the readings obtained in the twist-off test for this mortar type are about 38.5% higher than those attained in the friction-transfer test.

Figure (9) displays an example of the results obtained from the two abovementioned tests.

(a) Friction-transfer test's results

(b) Twist-off test's results

Figure (9): the results obtained from performing in-situ tests

It can be observed in figure (9) that the failure resulting from the twist-off test is very superficial and trivial and that the failure stemming from the friction-transfer test is about 20mm inside the core.

The Effect of Water-to-Cement Ratio on Cement Mortar's Strength:

According to the results obtained from the compressive, flexural and tensile strength tests of cement mortars, it was observed that the mortar with a lower ratio of water to cement (M1) has a higher strength in comparison to M2 mortar in such a way that the compressive, flexural and tensile strength rates of M1 mortar were averagely 1.19, 1.23 and 1.17 times those of the other mortar. Furthermore, the water to cement ratio exerts the same effect on the results obtained from twist-off and friction-transfer test methods. As for M2 mortar that contains more water, an amount of water remains inside the mortar when it becomes hard and this entrapped moisture is gradually evaporated and leaves empty spaces behind and these empty spaces cause reductions in concrete's strength. However, in M1 mortar, more water is consumed during hydration reaction due to the lowness of the water to cement ratio as a result of which a lot lesser water is left for evaporation and this means a lower number of cavities hence unreduced strength. Water to cement ratio is directly associated with the diameter of the cavities and their number inside the concrete and their increase cause a reduction in the compressive strength of the concrete [23]. In general, assuming a perfect density of the cement masonry at a certain age and in normal temperature hence full strength thereof, the water to cement ratio is in an inverse relationship with the strength [24].

Hydration of the cement is the result of a chemical reaction between the molecules of the primary cement and water constituents. The main reaction takes place between the silicates existent in cement, C_3S[3], and C_2S[4], with water (abbreviated as H) as shown below:

Hydration products are calcium silicate hydrates and calcium hydroxide. C-S-H is indeed in the form of $C_3S_2H_3$ with C, S and H respectively denoting CaO, SIO_2, and H_2O. Besides, CH composition is, in fact, the very $Ca(OH)_2$.

Calcium silicate hydrate, C-S-H, is a hard compound featuring a high strength in such a way that the compressive strength of the hardened mortar is essentially due to the C-S-H compound. C_3S rapidly enters chemical reaction in presence of water and hardens the mortar in such a way that a substantial part of its acquisition of strength in the early days of its life is due to the chemical reaction between water and C_3S. The acquisition of strength after seven days of age is more due to the reaction between C_2S and water. Failure in wetting the mortar prevents a considerable quotient of the chemical reaction between water and cement and the mortar cannot consequently reach the expected strength and hardness. In the case of imperfect and insufficient curing, the hardened mortar's compressive, tensile and flexural strength is reduced.

Figure (10) exhibits the images taken from mortar cured by soaking in water under a scanning electron microscope. It can be observed in Figure (10) that the preservation of moisture via performing curing methods prevents the cracks from formation inside the mortar and this causes the mortar's strength not to be decreased.

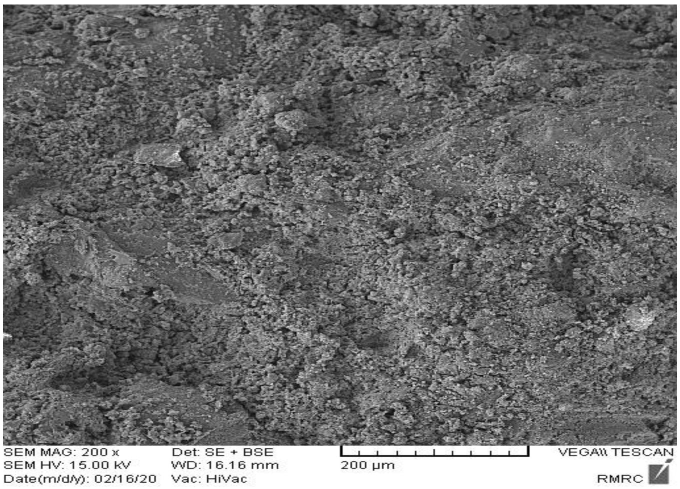


Figure (10): the result of imaging using scanning electron microscopy of post-curing mortar

Figure (11) displays the images taken from mortar left in open space under a scanning electron microscope. It can be seen in Figure (11) that the mortar's non-preservation of moisture causes cracking and creation of hollow and empty spaces that per se bring about declines in mortar's strength.

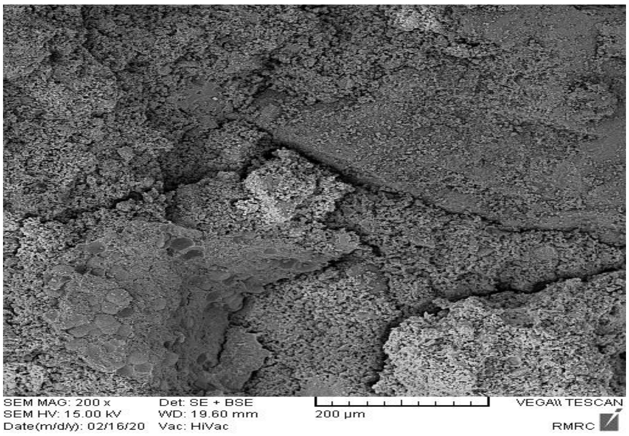


Figure (11): the result of imaging using scanning electron microscopy of mortar left in open space

The Ratio of Tensile-Flexural to Compressive Strength in Reparatory Mortars:
Table (3) gives the ratio of tensile-flexural to the compressive strength of M1 and M2 cement mortars.

Table 3: the ratio of tensile-flexural to the compressive strength of reparatory mortars (%)

		3-day			7-day			28-day			42-day			90-day		
		Water	Curing materials	Open space	Water	Curing materials	Open space	Water	Curing materials	Open space	Water	Curing materials	Open space	Water	Curing materials	Open space
Tensile to compressive	M1	8.2	8.1	7.1	8.5	8	7.4	8.3	7.7	6.8	7.9	7.8	6.7	8.4	8.2	7.4
	M2	8.1	8.1	6.9	8.3	7.8	7.1	7.8	7.5	6.5	7.6	7.3	6.6	8.2	7.9	7
Flexural to compressive	M1	27.4	31.4	63.4	24.9	27.4	30.1	19.6	21.5	23.9	18.8	21.4	24.1	18.7	21.7	24.2
	M2	28.7	32.3	37.1	25.2	27.8	29.9	19.4	21.8	23.9	19	21.7	24	19	22	24.2

It can be observed in Table (3) that the tensile strength is averagely about 7.64% of the compressive strength in the mortar and also that the ratio of flexural to compressive strength is equal to 24.9%. In another research on the tensile strength of the mortars, it was made clear that the ratio of tensile to the compressive strength of the mortars is equal to 7% [25].

Conclusion:

1) It was observed according to the obtained results that the twist-off and friction-transfer tests, as semi-invasive in-situ methods, are capable of evaluating the strength of the cement mortars with a high confidence coefficient.
2) The intensities of the correlation between the results obtained from the friction-transfer method and those attained in the compressive, tensile and flexural strength experiments on the cement mortars are equal to 98%, 96% and 93% indicating the high precision of this method in evaluating the mortar strength.
3) The intensities of the correlation between the results obtained from the twist-off test and those attained in the compressive, tensile and flexural experiments on the cement mortars are 96.6%, 94.3% and 89% indicating the high precision of this method in evaluating the mortar strength.

4) The results obtained from the friction-transfer test are reflective of lower values than those attained in the twist-off test due to pretest coring and the resultant cracks.
5) The results obtained from the twist-off test are about 35% higher than those attained in the friction-transfer test.
6) Performance of no curing causes a severe reduction in the mechanical properties of the mortars and it is due to the development of continuous cracks and creation of cavities inside the non-cured mortar as evidenced in scanning electron microscopy.

REFERENCES

1. ASTM C808/C805M-18. 2018Standard Test Method for Rebound Number of Hardened Concrete, ASTM International, West Conshohocken, PA
2. ASTM C597-16. 2016 Standard Test Method for Pulse Velocity through Concrete, ASTM International, West Conshohocken, PA
3. ASTM c42/c42m-18a standard test method for obtaining and testing drilled cores and sawed beams of concrete
4. Masi. A., Digrisolo. A., Santarsieo. G. 2013. arsiero, “Experimental evaluation of drilling damage on the strength of cores extracted from RC buildings, in Proceedings of World Academy of Science, Engineering and Technology, 7(7). p.749
5. ASTM C900-15. 2015 Standard Test Method for Pullout Strength of Hardened Concrete, ASTM International, West Conshohocken, PA
6. ASTM C1583, Standard test method for tensile strength of concrete surfaces and the bond strength or tensile strength of the concrete repair and overlay materials by direct tension (pull-off method), West Conshohocken PA, American Society for Testing and Materials (2004).
7. M., Naderi, “Assessing the In-situ Strength of Concrete, Using new Twist-off Method”, International Journal of Civil Engineering, Vol.4, No. 2, 146-155, 2006.
8. M., Naderi, “Friction-Transfer Test for the Assessment of in-situ Strength & Adhesion of Cementitious Materials”, Construction & Building Materials, 19 (6) (2005) 454-459
9. M., Naderi. S. A. Hajinasiri. Using Twist-off Method for Measuring CFRP/Concrete Adhesion When Exposed to Cyclic Temperature Changes, Wet-Dry and Freeze-Thaw, The journal of adhesion, 89:7, 559-577, 2013
10. M. Naderi (2008) Adhesion of Different Concrete Repair Systems Exposed to Different Environments, The Journal of Adhesion, 84:1, 78-104.
11. M. Naderi & O. Ghodousian (2012) Adhesion of Self-Compacting Overlays Applied to Different Concrete Substrates and Its Prediction by Fuzzy Logic, The Journal of Adhesion, 88:10, 848-865.
12. M. Naderi, An alternative method for in situ determination of rock strength, Can. Geotech. J. 48: 1901-1905, 2011.
13. M. Naderi, Evaluating in situ shear strength of bituminous pavements, Proceedings of the institution of Civil Engineering, pp 61-65, 2006
14. M. Naderi, R. SHibani. New method for nondestructive evaluation of concrete strength, Australian journal of basic and applied sciences, 7(2): 438-447, 2013.
15. ASTM C136-01, “Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates”, American Society for Testing and Materials, (2001).
16. ASTM C128, Standard test method for relative density (specific gravity) and absorption of coarse aggregate, West Conshohocken PA, American Society for Testing and Materials (2015).
17. ASTM C127, Standard test method for density, relative density (specific gravity), and absorption of fine aggregate, West Conshohocken PA, American Society for Testing and Materials (2012).
18. ASTM C109, Standard test method for compressive strength of hydraulic cement mortars (using 2-in. or [50-mm] cube specimens), American Society for Testing and Materials (2013).
19. ASTM C348-19, Standard test method for Flexural Strength of Hydraulic-Cement Mortars.
20. ASTM C190, Standard test method for tensile strength of hydraulic cement mortars (Withdrawn 1990), American Society for Testing and Materials (1985).
21. Virak Han, Soty Ros, Hiroshi Shima. Effects of Content, Superplasticizer Dosage, and Mixing Time on Compressive Strength of Mortar, 2014, ACI Material Journal
22. O, Cakir. F, Akoz. Effect of Curing Condition on the Mortars with and Without GGBFS, Construction and Building Materials 22 (2008) 308-314
23. Y, Kim. K, Lee. J, Bang. S, Kwon. Effect of W/C Ratio on Durability and Porosity in Cement Mortar with Constant Cement Amount, Advances in Materials Science and Engineering, 2014
24. Neville AM. J, J, Brooks, concrete technology. 2th Edition
25. Neville AM. Properties of concrete, 3rd ed. USA: Longman Scientific and Technical; 1992