Investigation of In-Situ Compressive Strength of Fiber-Reinforced Mortar and the Effect of Fibers on the Adhesion of Mortar/Steel

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Abstract: The proper connection between mortar and steel is one of the crucial issues in civil engineering. This paper has investigated the effect of polypropylene fibbers on the bond between cement mortar and steel, using “Twist-off” and “pull-off” tests. Moreover, in order to assess the in-situ mechanical properties of fibre-reinforced mortars, the correlation of records obtained from semi-destructive methods of “Twist-off” and “pull-off” with those of laboratory tests was determined, and calibration curves were provided, using the regression analyses. The mentioned tests were modelled with the ABAQUS software to evaluate the distribution of stresses and cracks developed during the semi-destructive tests. The results show that the addition of polypropylene fibbers reduces the shrinkage of mortars by about 13% and this has a direct effect on the bond between the mortar and steel. So that the shear and tensile bond of fibre-reinforced mortars at 90 days is 75% and 94% higher than conventional mortars, respectively. The reason for this is the effect of fibbers on the process of hydration of mortars and also to prevent excessive opening of cracks, which is shown by SEM. According to the results, instead of using an expensive and imported pull-off device, a cheap and internal twist-off device can be used to measure adhesion. Also, to evaluate the compressive strength of mortars, twist-off and pull-off tests can be used by placing the readings obtained in the equations $y = 0.156x + 0.329$ and $y = 0.055x - 0.001$ instead of x, respectively, to evaluate the compressive strength of mortars.

Keywords: Bond, Fibre, Finite Element Method, Mortar, Steel

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Research paper

1 INTRODUCTION

In every hybrid structure built with a combination of concrete and steel rebar, rehabilitation could be required based on a variety of reasons. In some parts of the structure, covered concrete laid on reinforced members such as beams, columns, floors, and so on may be crashed in which rebar becomes exposed; this could lead to rusting and corrosion of reinforcement and damage the concrete section. These parts need remediation that lots of time could be achieved by fulfillment using cement mortars. The amount of adhesion between the concrete and the steel rebar is so crucial in terms of both structural behavior and cracks due to shrinkage. A common problem caused by poor bond between mortar and steel is the shrinkage. In addition to the deformations caused by stresses, volumetric changes resulted from shrinkage or temperature changes are highly significant because these movements are usually not locally or completely restrained in practice, which leads to stress within the mortar. In general, cracks should be prevented, controlled and minimized; because a crack within the mortar is one of the main factors contributing to a reduction in the bond between the mortar and steel. The purposes of adding fibbers to the mortar are to delay cracking, and reducing the width of cracks. Fibbers sew the two edges of cracks, thus preventing their propagation, which results in reduced shrinkage. It is also necessary to know the mechanical properties of mortars for proper use in the right place. Therefore, nowadays, the tendency to determine the mechanical properties of materials by conducting in-site tests in the form of non-destructive or semi-destructive methods is increasing day by day.

As there is water in the capillary pores of hydrated cement pastes, it should be noted that immediately after the water removal from the capillary pores, the water is also removed from the surface and the shrinkage occurs [1]. Bond between the repair mortar and substrate under wet curing practices was about 3.5 times higher than that released in the open space [2]. A research study conducted on this found that adding polypropylene fibbers reduced dry shrinkage of the specimens [3]. However, in some research studies, it has been demonstrated that the addition of too much fibbers could produce defects in the properties of the cementitious materials [4-6]. Rupture in multilayer systems is often due to inconsistency between characteristics of the repair layer and substrate [7]. One of the important characteristics is shrinkage, as early shrinkage could result in cracks [8]. Shrinkage between two surfaces causes reduced adhesion between them and the occurrence of rupture at the interface [9-10]. The existence of some slight rusting on the surface of the steel bars results in mechanical adhesion [11]. Typically, the bond between surfaces is divided into adhesion, friction, and mechanical interference [12]. The adhesion is relevant to chemical connections. Friction happens when movements occur between surfaces; and mechanical interference is related to surface roughness. Also, there are various methods to determine the amount of bond strength between steel and mortars and assess the compressive strength of mortars, these include: friction-transfer test [13-15], twist-off [16] test, pull-off test [17], pull-out [18] and push-out test. It should be noted that the friction transfer test is also used to assess the compressive strength of concrete [19], bituminous pavements [20] and rock material [21]. In another study, to compare the twist-off method and the compressive strength of concrete cubic samples with different strengths, a correlation coefficient of 95% was obtained [22].

In practical work, the curing time is usually one week. However, the shrinkage of the mortar will continue after that. Therefore, in this paper, by adding polypropylene fibers to repair mortars, the effect of fibbers on the shrinkage of mortars has been studied and its effect on the adhesion between mortar and steel has been investigated. The almost new twist-off method has been used to measure the adhesion between mortar and steel, and by comparing the results of this test with the pull-off test, we have shown that to measure the adhesion between layers, instead of using an expensive and imported pull-off device, a cheap, easy and internal twist-off device can be used. Furthermore, due to the need to evaluate the compressive strength of cementitious materials at different ages and in situ, using the twist-off and pull-off tests, the compressive strength of repaired mortars has been evaluated. In this regard, calibration diagrams were drawn between laboratory tests and semi-destructive tests and linear equations are presented to convert the results of semi-destructive tests into the compressive strength of mortars. Also, due to the fact that twist-off test is an almost new method, so for its effect on mortars and distribution of stresses and cracks, modeling with ABAQUS software and numerical results were compared with laboratory results.

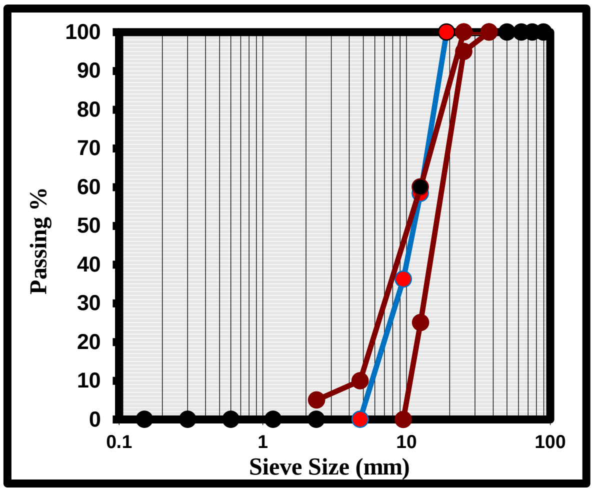
2 MATERIAL AND METHODS

2.1. Materials

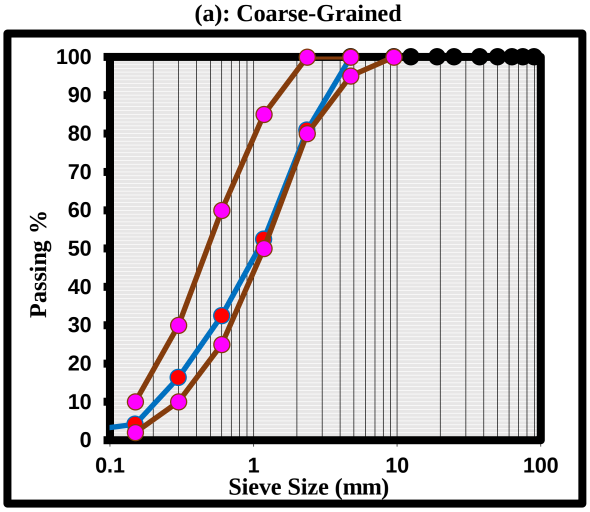
Type II cement, with a density of 3007 kg/m3, was used to make mortars. The densities of saturated surface dry sand is 2510 kg / m3, and their maximum sizes is 4.75 mm. Water absorption of sand is listed as 3.2% according to ASTM C127 [23]. The polypropylene fibbers with the specifications listed in “Table 1” were used. The fibbers were used with 0.3% mortar volume. Figure 1 shows the aggregate grading diagram. To process the samples, polyolefin curing agent and epoxy resin adhesive were used with the volumetric composition ratio of one to one, shear strength of 15 MPa, compressive strength of 70 MPa and Young's modulus of 12750 MPa.

Table 1 Fibers Specifications

Diameter (mm)	Length (mm)	Modulus of Elasticity (GPa)	Tensile Strength (MPa)	Special Weigth (Kg/Litr)
0.022	12	7	380	0.91



(a): Coarse-Grained



(b): Fine-Grained

Fig. 1 Aggregate Grading Diagram.

The schematic of the repair mortar mixture is illustrated in "Table 2" .

Table 2 Specifications of mortars

W/C	Sand/Cement	Specific name
0.5	1 : 3	M1
0.5	1 : 2	M2

2.2. Laboratory Methods

ASTM C157 [24] and ASTM C490 [25] standards were used to measure the shrinkage of repair mortars, and the value of shrinkage can be measured based on the percentile from "Eq. (1)" :

$$L = \frac{L_x - L_i}{G} \times 100 \qquad (1)$$

Where, L is the length change of the sample, Li is initial sample reading minus Reference rod reading, Lx is the sample reading minus Reference rod reading and G is Reference rod length. The ASTM C109 [26] standard was utilized to measure the mortar compressive strength, and the average of six 50 mm cubic samples was calculated for each sample. The pull-off method was used to determine the tensile bond strength between repair mortar and steel substrate. This method was also used to evaluate mortar compressive strength.

In the "pull-off" test, to determine the bond between the mortar and the steel, a core with a 50mm diameter is first mounted on the test surface using a diamond drill bit and a metal cylinder with a diameter of 50 mm and a thickness of 20 mm is attached to the partial core. Then, the tensile force is applied to the cylinder by means of a "pull-off" device to make the partial core fail ("Fig. 2a"). Furthermore, according to "Fig. 2b" , the aforementioned metal cylinder is attached to the mortar surface and tensile force is applied to it without coring to determine the relationship between the results of the "pull-off" test and the compressive strength of repair mortars.

(a): Bond strength

(b): Mechanical properties

Fig. 2 Performing the "pull-off" test.

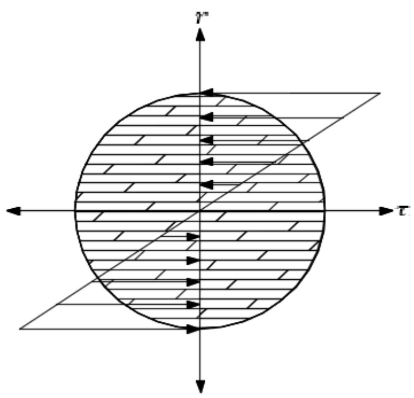
The twist-off test was applied to determine shear bond strength. In the twist-off test, the core drilling machine first created a partial core from the mortar to the substrate steel surface, then the steel cylinder was bonded to the core surface using Epoxy resin-based adhesives, and a conventional torque wrench inserted a twisting moment into the steel cylinder to separate the core from the steel surface ("Fig. 3a"). Moreover, in order to evaluate the mortar compressive strength, 150 mm cubic samples were made and a steel cylinder was adhered to the surface without core drilling; after which a twisting moment was inserted into the steel cylinder by using Torsion Testing Machine to separate crushed mortar and the cylinder from mortar surface ("Fig. 3b").

(a) Bond strength

(b) Mechanical properties

Fig. 3 Performing the "twist-off" test.

As can be seen in "Fig. 1a" , the partial core is a cylinder with a circular cross-section in this method. As it is evident in "Fig. 4a" , if the twisting moment is applied, maximum shear stresses will occur on the circumference of the circle that has the furthest distance from the centre. The failure between common surfaces has different forms: failure occurs at the common boundary between the repair mortar and the steel substrate ("Fig. 4b") or failure occurs within the mortar ("Fig. 4c"). Given that maximum stress occurs at the farthest distance from the centre if a composite failure occurs, "Fig. 4c" shows that failure did not occur at the centre but at the farthest distance from the centre.



(a): Maximum shear stress

(b): Failure at common boundary

(c): Composite failure
Fig. 4 Creation of Stress and Failure in the "Twist-off" Method.

The maximum shear stress created by the twist-off method is calculated as "Eq. (2)" .

$$\tau_{E-max} = \frac{Tr}{J}, J = \frac{\pi r^4}{2} \rightarrow \tau_{E-max} = \frac{2T}{\pi r^3} \quad (2)$$

Where, r is the radius of the partial core and J is the polar moment of inertia.

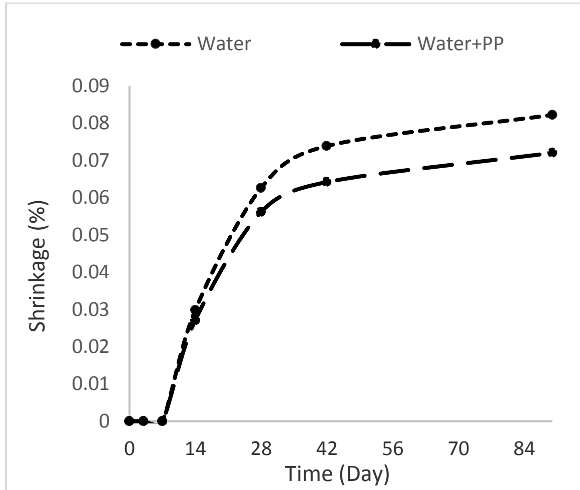
Making the Samples

The samples were placed in water and the curing agent for seven days. When the process was complete they were removed and tested again at 7 and 90 days later. Additionally, to evaluate the mortar compressive strength 150 mm mortar cubic samples were built simultaneously through semi-destructive twist-off and pull-off methods. When the process was complete, they were removed and tested again at different periods.

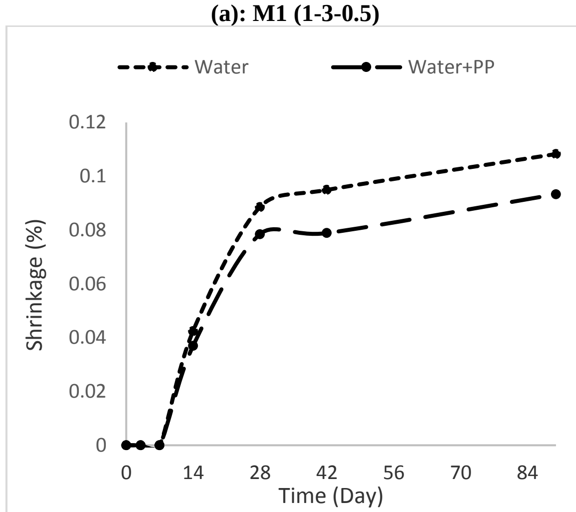
3 RESULTS AND DISCUSSION

3.1. Dry Shrinkage

Figure 3 illustrates the dry shrinkage of repair mortars with and without fibres at different ages. The results indicate that the shrinkage of all mortars starts after leaving the curing practices. Over time, the shrinkage of mortars increases. The process of shrinkage is accelerated because of the moisture outflow from the mortar, the outflow of free water from mortar and then the outflow of adsorbed water during the week of curing practices. Figure 5 demonstrates that the addition of polypropylene fibres to both mortars reduced dry shrinkage. Therefore, the mean 90-day shrinkage of M1 and M2 mortars containing polypropylene fibres was 11.1% and 14.3% lower than mortar without fibres, respectively. It was also observed that shrinkage was very high at an early stage, and the rate of shrinkage decreased over time. It was noted in another study conducted on mortar shrinkage that the rate of shrinkage peaked in the first 42 days and then drastically declined, especially after 90 days [27].



(a): M1 (1-3-0.5)



(b): M2 (1-2-0.5)
Fig. 5 Mortars Shrinkage.

Due to the positive effect of polypropylene fibres on the shrinkage of repair mortars, the effect of this shrinkage reduction on the shear and tensile bond strength is evaluated between the repair mortar and steel substrate. Also, a comparison of diagrams A and B in "Fig. 5" illustrates that M1 mortar has less shrinkage than M2 mortar. Since M1 mortar has a higher aggregate-to-cement ratio, and more aggregate in the mortar is an influential factor in reducing shrinkage, it will have less shrinkage compared with M2 mortar that has less aggregate and more cement. The amount of 90-day shrinkage of the mortar with a mixing design of 1-2-0.5 is 31.5% more than the mortar with a mixing design of 1-3-0.5. This is due to less aggregate and more cement paste.

3.2. Shear Bond Strength Resulting from "Twist-off" Test

Figure 6 illustrates the results of the twist-off test used to determine the shear bond strength for M1 mortar.

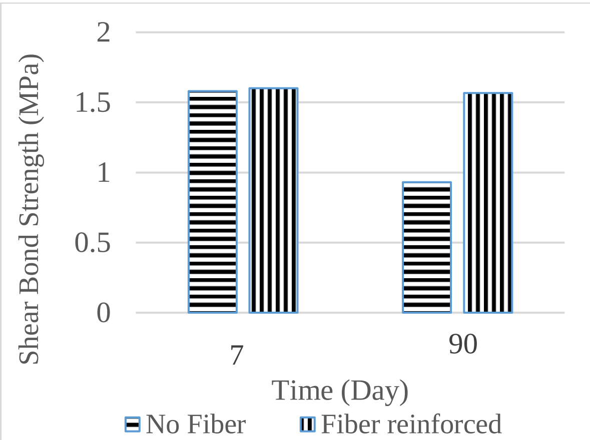


Fig. 6 Results of the "Twist-off" Test for M1 Mortar.

It is observed that adding polypropylene fibres to the mortar significantly increases the shear strength of the repair layer with the steel substrate. However, there is little difference between their strength at the age of 7 days when the samples have just been processed and extracted. The addition of fibre to the mortars cured with water increased shear bond strength between the repair mortar and steel substrate to 68.5% at age of 90 days. Compared to mortars without fibres, the increase in shear bond strength of mortar with fibres is due to the increased crack width control and fibre shrinkage.
Figure 7 illustrates the results of the twist-off test to determine the shear bond strength for M2 mortar.

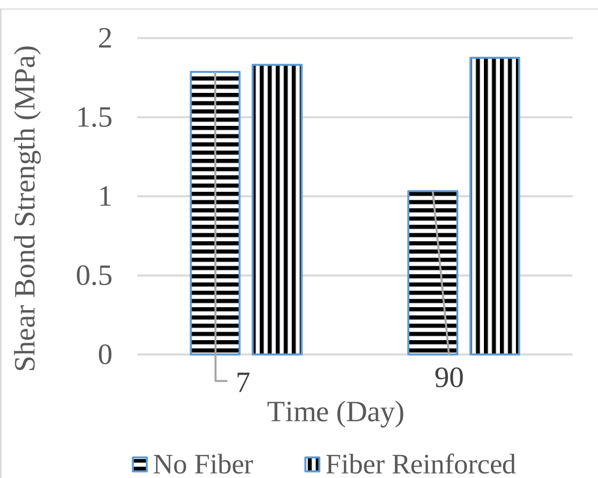


Fig. 7 Results of the "Twist-off" Test for M2 Mortar.

As illustrated in "Fig. 7", similar to M1 mortar, it can be observed that adding fibres to the mortar significantly increases the bond strength. A comparison of mortars with and without fibres indicated that the shear bond strength of the samples with fibres, cured with water, was 81.6% higher than the samples without fibres at the age of 90 days.

3.3. Tensile Bond Strength of "Pull-off" Test

Figure 8 illustrates the results of the pull-off test used to determine the tensile bond strength for M1 mortar.

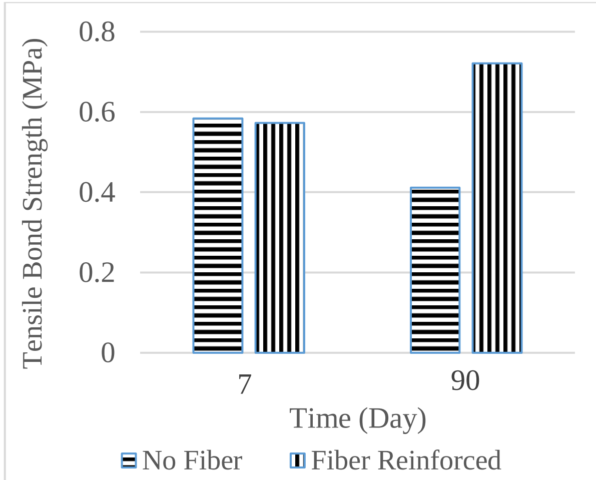


Fig. 8 Results of the "Pull-off" Test for M1 Mortar.

It was observed that adding polypropylene fibres to the mortar significantly increases the tensile strength of the repair layer with the steel substrate. However, there was little difference between their strength at the age of 7 days when the samples had just been processed and extracted. Adding fibre to the mortars cured with water increased the tensile bond strength between the repair mortar and steel substrate to 75.2% at age of 90 days. The evident improvement in tensile bond strength in the mortar with fibres is due to the increased crack width control and fibre shrinkage.
Figure 9 illustrates the results of the pull-off test used to determine the tensile bond strength for M2 mortar.

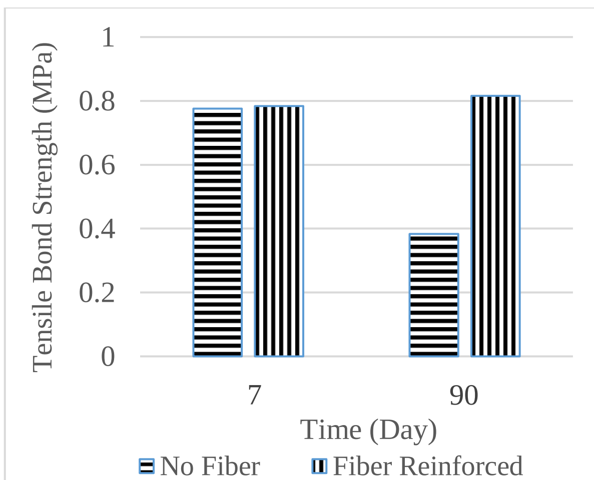
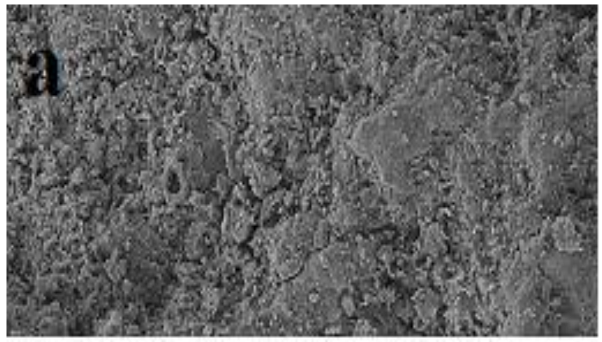


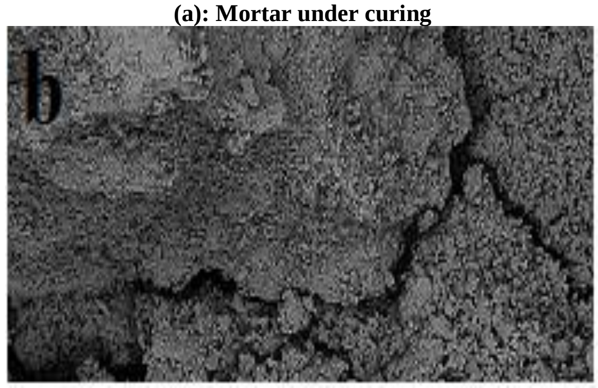
Fig. 9 Results of the "Pull-off" Test for M2 Mortar.

Similar to results obtained for M1 mortar, it was observed that adding fibres to the mortar significantly increases the bond strength, see "Fig. 9". A comparison of mortars, those with and without fibres, indicated that the tensile bond strength of the samples with fibres and cured with water was 113% higher than the samples without fibres at the age of 90 days. Overall, the data shown in "Figs. 6 to 9" indicate that adding fibres to mortars has a significant effect on the shear and tensile bond strength between the repair mortar and steel substrate, resulting in a general improvement. It is also observed that the difference in the amount of 7-day adhesion for ordinary mortars and fibre-reinforced mortars is very small. However, the adhesion of these two types of mortars at the age of 90 days is very high. Due to the fact that the mortars have been cured in water for 7 days, so in this time, there has been no shrinkage in the mortars, and therefore the fibres have not had much effect on the adhesion between the mortar and the steel. But at the age of 90 days, the fibre-free mortars have shrunk a lot and therefore their adhesion resistance has decreased. However, for fibre-reinforced mortars at the age of 90 days, the fibres prevent the cracks from opening too much inside the mortar, which prevents the falling of adhesion between the mortar and the steel. Therefore, at the age of 90 days, a big difference between the adhesion of ordinary mortars and fibre reinforced mortars is seen.

Experimentally obtained results indicate that most failures occurred at the common surfaces between the repair mortar and steel substrate; and that the composite failure only occurred in a very limited number of samples, and did not occur at the boundaries between the surfaces. Therefore, it has little effect on the results and can be disregarded. Subsequently in this section, the mortar was scanned by a scanning electron microscope and the cracks inside the mortars were exposed when the mortars were cured and extracted. The cured mortar does not experience shrinkage and cracking, as illustrated in "Fig. 10a" , which results in increased bond strength between the repair mortar and steel substrate. On the other hand, as illustrated in "Fig. 10b" , the cured and extracted mortar begins to shrink due to water outflow from the capillary pores, as well as the loss of adsorbed water, which results in cracks inside the mortar; this is the primary reason for the decrease in bond strength between the repair mortar and steel substrate.



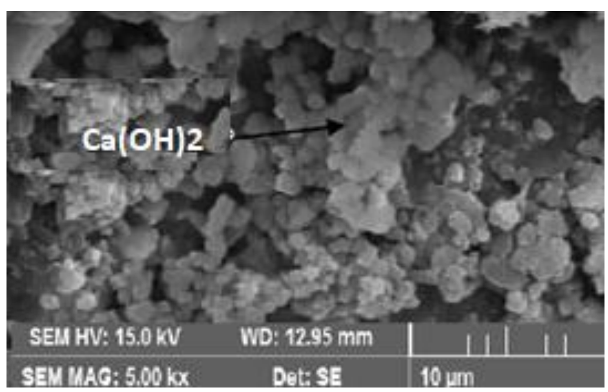
(a): Mortar under curing



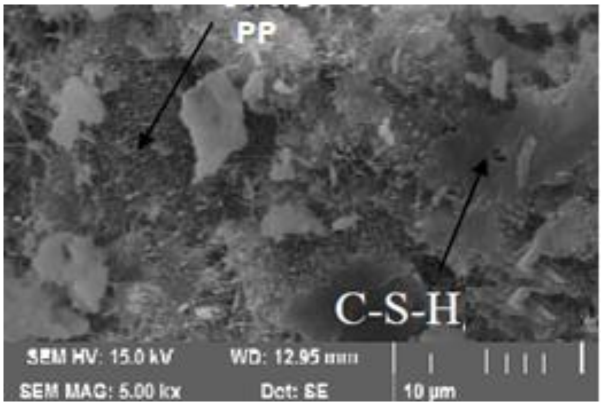
(b): Cracking of mortar

Fig. 10 Scanning Mortar by using Scanning Electron Microscope.

The Scanning electron microscopy imaging was used to evaluate the microscopic structure of mortars. Figure 11 illustrates the Scanning electron microscopy image of the mortar without fibres. As can be seen in "Fig. 11a" , the C-S-H silicate gel was formed from the hydration of C3S and C2S, but there were void spaces in the mortar, which could significantly reduce its mechanical properties. As seen in "Fig. 11b" , with the addition of polypropylene fibres to the mortar, the process of cement hydration and formation of C-S-H silicate gel, along with polypropylene fibres, was conducted well and resulted in better homogeneity of the mortar mix. In other words, the addition of the polypropylene fibres resulted in better bond of the mortar.



(a): No fibre



(b): fiber reinforced

Fig. 11 Effect of fibers on the hydration mortars.

Figure 12 shows the correlation coefficient between the results of the twist-off and pull-off test to measure the bond strength between fibre-reinforced mortars and steel.

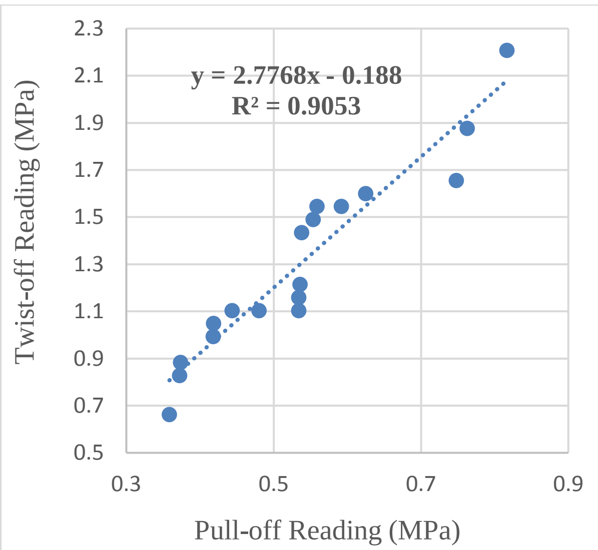


Fig. 12 Twist-off and Pull-off correlation.

According to the "Fig. 12", the determination coefficient of "pull-off" and "twist-off" tests is 0.905. In addition, the correlation coefficient of two mentioned tests is 0.95. Considering the high correlation coefficient of the results of "pull-off" and "twist-off" tests, it is possible to obtain the results of one test and consider it for the other test. Therefore, the simple and cheap machine of the "twist-off" test can be used instead of the expensive machine of the "pull-off" test for determining the bond strength between the substrate and the mortars.

3.4. Evaluation of the Compressive Strength of Mortar

To evaluate the compressive strength of mortars with and without fibres on different days, a quantity of 150 mm cubic samples were made, placed into water. The samples were then extracted and tested using the twist-off and pull-off tests at the ages of 7, 28, 42 and 90 days. The results of the tests were compared with the compressive strength of the 50 mm cubic samples. The compressive strength of the cubic samples is presented in "Table 3" .

Table 3 The Results of Compressive Strength of Samples (MPa)

		7 Days	28 Days	42 Days	90 Days
Compressive Strength	Plain	34.1	47.6	51.2	54.4
	+ PP	35.8	50.4	53.1	56.6

As presented in "Table 3" , the compressive strength of the repair mortars has been improved by adding 0.3% fibres. Adding fibbers to repair mortars in the samples cured in water increased the compressive strength on average by 4.6%. Fibbers were added to the cement mortar to increase the strength, delay cracking in the stress-strain mortar, and transfer stress along the crack width so that the mortar with fibre can withstand greater deformation under stress.

Figure 13 presents the compressive behavior of ordinary and fibre-reinforced mortars. The sample containing polypropylene fibbers failed at the stress of 48.8 MPa, while the ordinary mortar without fibbers failed at the stress of less than 46 MPa. Moreover, the deformation tolerated by the mortar with fibre is 0.0142 at the peak of stress, whereas it is lesser for fibbers without mortar (about 0.0098), which is about a 45% reduction.

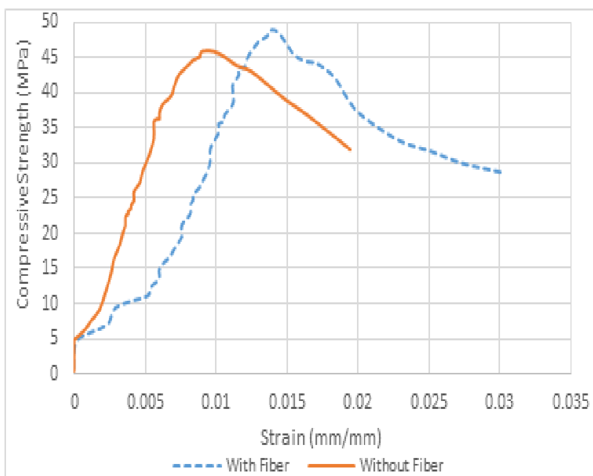
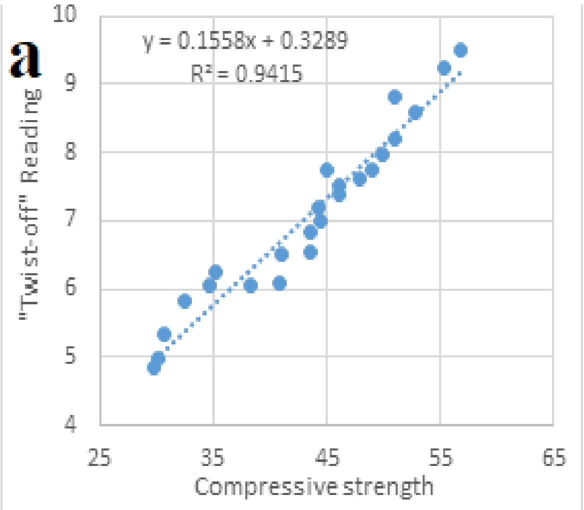
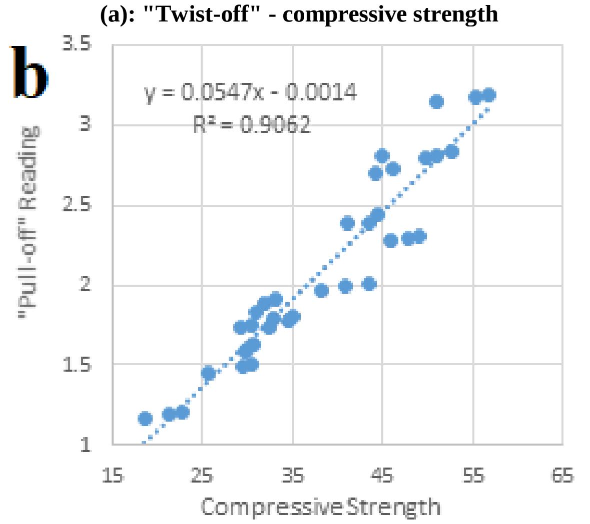


Fig. 13 A Comparison of compressive behavior.

Figure 14 illustrates the coefficient of determination and the correlation between the compressive strength of mortars with the twist-off and pull-off tests.



(a): "Twist-off" - compressive strength



(b): "Pull-off" - compressive strength

Fig. 14 Correlation between the results.

Figure 14a illustrates that the correlation coefficient and coefficient of determination between the results of the twist-off test and the compressive strength of the repair mortar were 95% and 91%, respectively. Also, the coefficient of determination and correlation coefficient between the results of the pull-off test and the compressive strength were 84% and 91%, respectively. Due to the strong correlation coefficient between the results of twist-off and pull-off tests, with the compressive strength of the repair mortar, the compressive strength of mortars can be easily evaluated by using the above-mentioned tests under different conditions.

Owing to the fact that the twist-off and pull-off tests are considered to be semi-destructive tests, practicing these tests leads to failure in the test object itself. Consequently, by increasing the age of the sample, and also the strength of the samples, the results of the in-situ methods increase. In time, and as the hydration process within the mortar cures, their compressive strength increases. Additionally, over time, more force is required to separate the steel cylinders utilized in the twist-off and pull-off tests, which are directly affixed to the surface of the mortar, from the surface of the mortar. This caused a failure in the sample. Accordingly, by increasing the compressive strength of samples, the results of the in-situ methods also increased, and this led to a high determination coefficient between the mechanical specification of samples, and the results of in-situ methods.

3.5. Numerical Modeling of Pull-off and Twist-off Tests

In numerical modeling, the precise definition of the material behavior in tension and compression can have various effects on the results obtained in the finite element software. A concrete damage plasticity model is a technique that can demonstrate the non-linear behavior of quasi-brittle material, such as concrete. In this model, the compressive behavior should include the complete elastic-plastic behavior of the concrete in its compression strain softening. Also, the tensile behavior should define the properties of concrete in elastic-plastic phases in tensile softening and hardening. In this section, the twist-off and pull-off tests were modeled using a concrete damaged plasticity model. After introducing materials and stress-strain curves, meshing element types should be specified and mesh convergence should be examined, because the problem converges to a single solution by reducing the dimensions of the elements. Responses were converged with elements between 2, 1 and 0.5 mm; however, a 1 mm element was selected in this study. In the twist-off and pull-off tests, the mesh of the cubic piece was a combination of the C3D8R and C3D4 elements. The core of the cylinders had an 8-node cubic element with reduced integration (C3D8R). Adhesive and steel pieces had the size of a 2 mm element. Figure 15 is an illustrated example of the elements of cubic pieces.

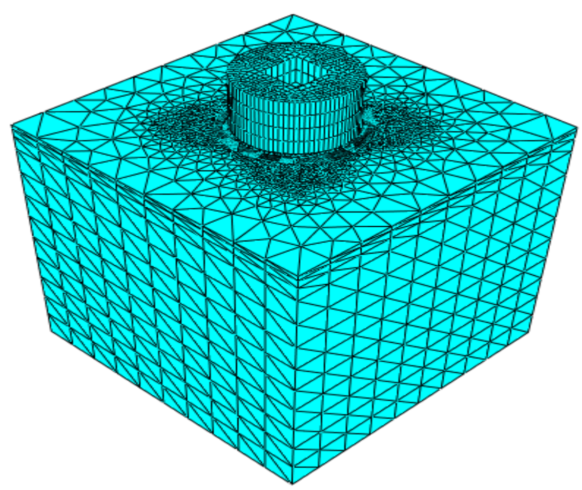
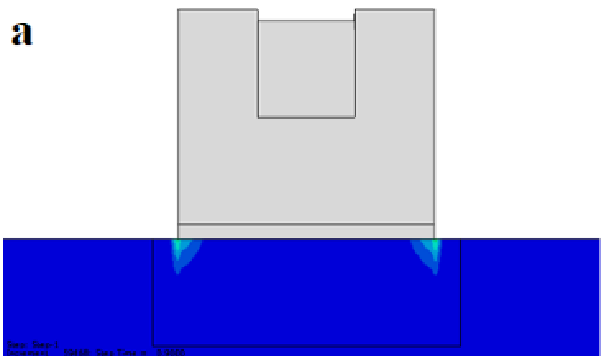


Fig. 15 The Elements of the Samples.

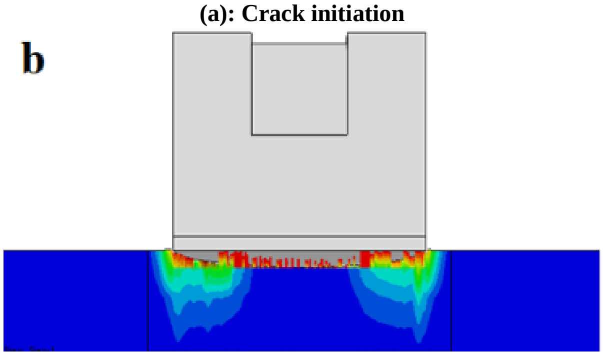
The behavior of two types of mortar, with and without fibre, was used to model twist-off and pull-off tests in ABAQUS software. As shown in “Table 3” , the sample containing polypropylene fibbers has a 28-day compressive strength of 50.4 MPa and the sample without fibre has a compressive strength of 47.6 MPa. Laboratory results of the twist-off test were 180 Nm for samples without fibbers and 190 Nm for samples containing polypropylene fibbers. Additionally, the results of the pull-off test were 4500 N and 4750 N for the samples without and with the fibbers, respectively.
In the twist-off test, the first cracks occurred at the edges of the samples which were under the Maximum torque. The initial damages occurred at 125 Nm in the typical mortar sample. As the torque was increasing, the damage also increased. When the torque reached 177 Nm, the final damage occurred. In the fibre mortar, damages started at 139.4 Nm and final failure occurred at 185 Nm. It was observed that the mortar with fibbers will tolerate more torque and then face failure. Furthermore, the results of modeling with Abacus finite element software are highly consistent with the results of the twist-off test conducted in the laboratory. Figure 16 illustrates an overview of the crack initiation and the final failure in samples.

a



(a): Crack initiation

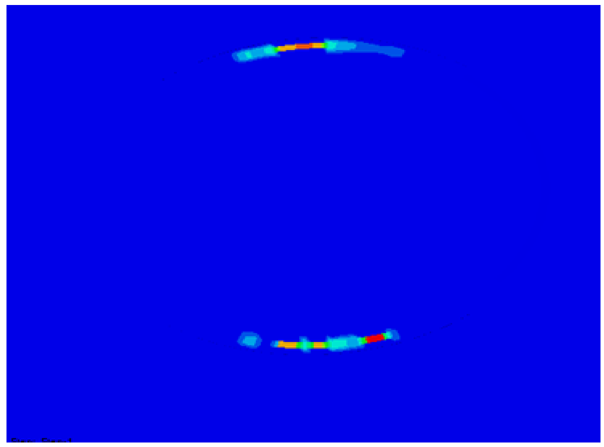
b



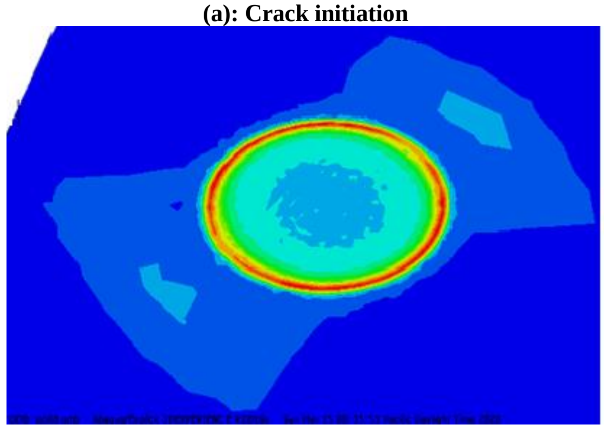
(b): The moment of failure

Fig. 16 An overview of the stresses in the “Twist-off” test

In the pull-off test, in the sample without fibre, the initial cracks occurred at 2248 N at the edges of the cylinder-mortar joint; whereas in the sample with fibre, the initial cracks appeared at 2701 N at the edges of the piece. The increase in force is linear and failure occurs momentarily in the piece when the ordinary mortar model has reached critical load at 4555 N and the fibre mortar model can bear up to 4905 N. It was observed that the fibbers in the mortar improved its behavior. Furthermore, there was a high degree of consistency between the experimentally obtained results of the pull-off test in the laboratory and the results of modeling.
An overview of the crack initiation and the final stress in the samples are illustrated in “Fig. 17”.



(a): Crack initiation



(b): Maximum tress under the cylinder

Fig. 17 An overview of the stresses in the "pull-off" test.

“Table 4” shows the results of laboratory tests and numerical results.

Table 4 Comparison of laboratory tests and numerical results.

methods	Experimental	Numerical
Twsit-off	190 N.m	185 N.m
Pull-off	4905 N	4750 N

“Table 4” shows that there is a high correlation between the results of laboratory tests and numerical results.

4 CONCLUSION

1- In conclusion, adding polypropylene fibbers to the repair mortar reduces the dry shrinkage and improves bond strength between the repair mortar and steel substrate.
2- The 90-day shear and tensile bond strengths between conventional repairing mortars and steel are 0.98 and 0.4 MPa, respectively. The two mentioned values between fibre-reinforced mortars and steel rebar have demonstrated 75.1 and 94.1 percent increase, respectively.
3- Considering the high correlation coefficient of the results of "pull-off" and "twist-off" tests, therefore, the simple and cheap machine of the "twist-off" test can be used instead of the expensive machine of the "pull-off" test for determining the bond strength between the substrate and the mortars.
4- The twist-off and pull-off tests can be used as a semi-destructive and functional test to evaluate the compressive strength of mortars with and without fibbers at different ages and in situ.
5- To evaluate the compressive strength of repair mortars, twist-off and pull-off tests can be used by placing the readings obtained in the equations $y = 0.156x + 0.329$ and $y = 0.055x-0.001$ instead of x, respectively.
6- The results of numerical modeling with ABAQUS software were largely consistent with the experimentally obtained results of the laboratory tests, with only a slight difference between them.
7- The examination of the compressive behavior of the mortars and the results of numerical modeling showed that the addition of fibbers improved the mortar behavior and increased the strength of mortar by tolerating greater deformation at peak stresses.

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