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ORIGINAL RESEARCH

The effects of pre-compress on the mortar/concrete bond and their in-situ compressive strength using "pull-off" and "twist-off" methods

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Abstract

The paper aimed to quantify the compressive strength of cementitious materials using in-situ "pull-off" and "twist-off" tests. Apart from determining the correlation coefficient, calibration plots and equations are presented to convert the results of in-situ tests to mortar compressive strength. The crack distribution was calculated in the tests using the nonlinear ABAQUS software. Additionally, the methods mentioned above were used to investigate the effect of pre-compression on mortar/concrete shear and tensile adhesion strength. Thus, the effect of pre-compression on the tensile and shear adhesion strength of mortar/substrate concrete was investigated using the scanning electron microscopy (SEM) method and physical adsorption theory. The results indicated that pre-compression positively affected adhesion and could be measured using the simple twist-off machine instead of the other machine. By applying 0.1 kg/cm^2 of pre-compress, the tensile and shear adhesion between the mortar and concrete layers increased by 5.8% and 8.8%, respectively, after 90 days. Additionally, a linear relationship between the results of "twist-off" and "pull-off" tests and those obtained from experimental tests was observed.

Keywords: Mortar, Pre-compress, adhesion, Twist off, Pull off.

Introduction

One factor contributing to the mortar's adhesion to the concrete is the method in which the repair mortar is compacted when applied to the concrete substrate. The interface between the mortar and the substrate is critical because improper compacting results in the formation of microscopic voids at the interface, which is one of the primary factors affecting the bond strength. According to research on the effect of compaction operations on the compressive strength of self-compacting concrete, proper compression increases the compressive strength of the material by approximately 5% [1].

Other research evaluating the compressive strength of various compacted concretes

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concluded that the Schmidt, Ultrasonic, and Extraction hammer tests demonstrate a strong influence on the compressive strength results [2]. Furthermore, other research on the effect of compression on the strength of ordinary concrete has revealed that the appropriate density increases compressive strength by between 4 and 8 MPa [3]. There are various processes for strengthening the bond between mortar and concrete. This field has been the subject of extensive research studies. The shrinkage of repair mortars is one of these variables.

The shrinkage that occurs during the mortar setting process is caused by the loss of humidity near the surface. Given that the hydrated cement paste contains capillary pores that contain some water, shrinkage occurs when the moisture in the pores is removed [4]. According to research, the growth of early fractures in multi-layer concrete systems is primarily due to a lack of compatibility between the characteristics of the repair layers and the substrate concrete [5]. Drying shrinkage is one of these characteristics.

According to some researchers, the difference in shrinkage values between the repair layer and the existing concrete at the joint is the primary cause of adhesion loss between the two systems [6]. Even though cementitious mixtures are generally shrinkage-resistant [7], the early setting of concrete results in material shrinkage and the formation of microscopic cracks on the concrete surface [8]. Cracks may also occur in concrete members that adjacent members constrain due to stresses caused by excessive shrinkage [9]. Wet curing can be an effective method of preventing moisture loss from the mortar. According to one study, the adhesion between concrete and uncured mortar is reduced by approximately 3.5 times [10].

Cement mortars have a variety of uses, including repairing concrete elements that have been damaged by a variety of physical or chemical conditions. Thus, it is critical to understand the specifications of cementitious materials to use them appropriately in the appropriate location. There are three types of tests currently available for determining the specifications of cement materials: “non-destructive,” “semi-destructive,” and “destructive.” While core drilling [11] and the “pull-out” method [12] are destructive, they have several disadvantages, including element damage and high costs. Non-destructive tests, such as the Schmidt hammer test [13] and ultrasonic testing [14], can be used to evaluate certain concrete and mortar specifications. By causing minimal damage, semi-destructive methods can produce excellent results for material strength. Between in-situ tests, pull-off tests [15], and twist-off tests [16], and tests are well-established.

In previous studies, twist-off test has been also employed to assess compressive strength of some cement materials including concretes and mortars. In a study for compressive strength measurement of polymer-modified mortars, it was found that there is a correlation coefficient of 94% between twist-off test and polymer-modified mortars [17]. In another study on measuring the compressive strength of different types of rocks used in concrete, it was found that the correlation coefficient is about 90% between the compressive strength of rocks and the twist-off test results [18]. In surface strength measurement of conventional and fiber concretes, it was found that there is a high correlation coefficient of 95the % between results obtained from the twist-off test and those from concrete breaker Jack [19-20]. In a study using twist-off test observed that there is a strong correlation between surface strength and permeability in concretes [21]. The correlation coefficient between twist-off and pull-off tests with compressive strength of fiber-reinforced mortar reaches up to 92% [22].

Recent research has focused on the mechanical properties of cementitious materials. Various sand/cement (S/C) and water/cement (W/C) ratios have a significant effect on the mechanical specifications of cementitious mortars, according to research on the effect of mix design ratios on defining the mechanical specifications of cementitious mortars [23]. Another study found that the ratio of W/C has an inverse relationship with the tensile strength of cementitious mortars [24]. Increases in the W/C ratio result in a 1.5-fold increase in the internal porosity of mortar [25] and a decrease in mortar strength.

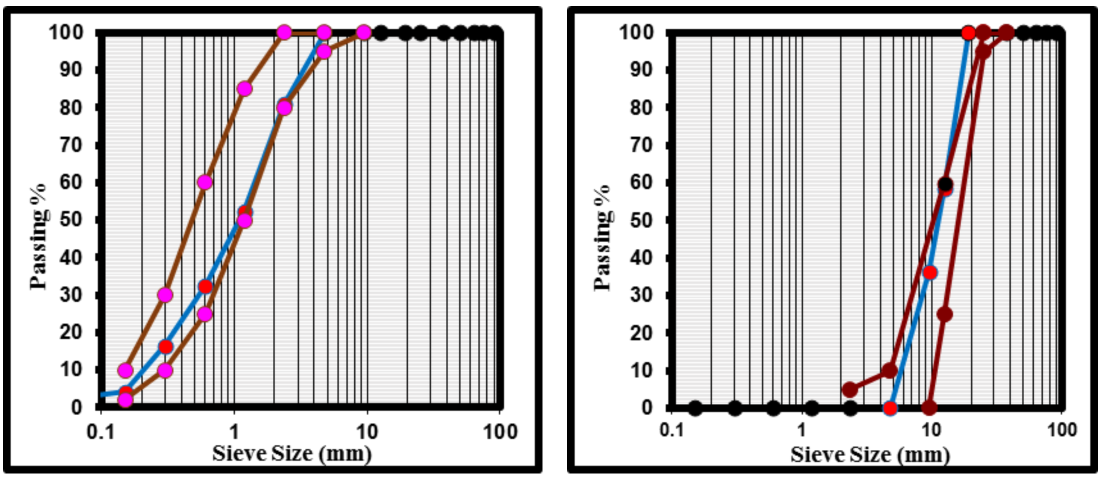
In this paper, a novel inventive method called “twist-off" was employed to measure the adhesion between repair mortars and concrete substrate. Pull-off test is a common method to measure adhesion. However, this test requires an expensive apparatus that has not been manufactured in Iran. Therefore, it must be imported expensively. Conversely, twist-off test requires simple, cheap, and easy access apparatuses. Furthermore, as mortar shrinkage causes shear strength along with the repair/ concrete substrate interface, the measurement of the twist-off test is more accurate. This is because the twist-off test directly measures shear strength between two substrates, while the pull-off test measures tensile strength. Regarding high correlation coefficients between the results, it is proposed to employ the twist-off method with simple, cheap, and available equipment instead of the pull-off test which requires imported and expensive apparatus. In this study, a pre-stress on repair mortar was applied in an innovative method. Moreover, the results of the adhesion between mortar and concrete was assessed. For instance, in cases that the mortar vibration is impossible due to low thickness of the repair layer, this method could be applied to prevent cohesion loss between the repair layer and concrete substrate.

In this paper, various pre-compresses were applied to repair mortars, and their effect on the bond strength of the joint surface was evaluated to improve the bond between the mortars and the substrate concrete. Additionally, the effect of curing the mortar and applying pre-compression on the adhesion between the mortar/concrete has been investigated using physical absorption theory and SEM. Meanwhile, the compressive strengths of materials were specified quantitatively using experimental methods and pull-off, twist-off techniques. In addition to measuring the correlation coefficient, calibration diagrams and equations for converting the pull-off and twist-off methods to the strength of repair materials have been presented. The crack distribution in the in-situ tests mentioned previously was calculated using the ABAQUS-Software.

2. Lab operations

2.1. Specification of materials

The mortar and concrete samples were prepared using gravel and sand with 19- and 4.75-mm aggregate sizes, respectively. According to the ASTM C127 standard [26] and the ASTM C128 standard [27], the water absorption capacity of sand and gravel was 3.2 and 2.6, respectively. Gradation diagrams for aggregates were provided per the ASTM C136 standard [28], as illustrated in Fig. 1.



a) Sand **b) Gravel**

Fig. 1. Gradation chart

Cement type 2 is used in the formulation of mortar and concrete mixes. In-situ methods require using a two-component epoxy resin to adhere metal cylinders to samples (Table 1). Polyolefin-based curing agents were used.

Table 1. Specifications of epoxy

Elasticity module	7 days compressive strength	Shear strength	Retention time		Curing time	
			35 ºC	25 ºC	35 ºC	25 ºC
12700 MPa	76 MPa	17 MPa	4.5 hr	10 hr	55 min	85 min

In addition, 150 mm Cubic speciments with a 28-day compressive strength of 58 MPa were used to build the substrate concrete; their mixing pattern is shown in Table 2.

Table 2. Concrete substrate weight ratios (Kg)

Super plasticizer	W/c	Water	Sand	Gravel	Cement
2.6	0.36	188	836	665	535

2.2. Making samples

The cement/sand ratio in repairing mortars is 1:2. In one mortar, the water/cement ratio was 0.4 (M1), while in the other, it was 0.5 (M2). The mortar samples required for the twist-off, pull-off, and experimental tests were placed in "water," "curing agents," and "open space" curing solutions. They were then tested at 3, 7, 28, 42, and 90 days. A total of 612 samples were tested.

To determine the mortar's adhesion to the substrate concrete, 25mm thick mortars were applied. The mortars were then subjected to compressive loads of 0.1, 0.5, 5, and 10 kg/cm^2 for 24 hours using 25, 100, 1100, and 2250kg weights, respectively. Compressive loads of 5 and 10 kg/cm^2 were applied mechanically, whereas compressive loads of 0.1 and 0.5 km/cm^2

were applied manually, as shown in Fig. 2. The specimens were cured in water for 7 days before being placed in an open space. The tests were performed at 7, 42, and 90 days.

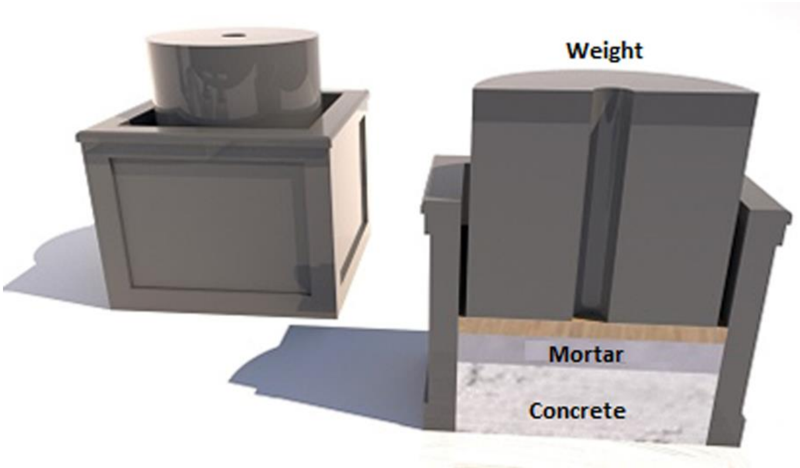


Fig 2. Pre-compress on the mortar surface

2.3 Experimental Methods

Steel cylinders with a radius of 25 mm were attached to the test surface to determine the compressive strength of the materials using the twist-off method. Then, as shown in Fig. 3a, a torque meter was used to apply a torsional moment to the cylinder, causing it to separate from the mortar. Furthermore, a steel cylinder with a radius of 25 mm was adhered to the surface of the mortar to evaluate the strength via the pull-off method. Afterward, the cylinder was subjected to a tension load via a machine, causing it to separate from the mortar surface, as illustrated in Fig. 3b.

a) Twist off method **b) Pull-off method**

Fig 3. Compressive strength assessment

To determination the shear bond between layers by using the twist-off method, it is required to drill a core on the repair surface at a depth of nearly 5 cm into the concrete. Then, a steel cylinder is attached to the core. A typical torque meter is employed to apply torsional moments to the steel cylinder so that the core undergoes fracture (Fig 4a). Based on the ultimate torsional moment, the adhesion strength is calculated using the relevance among the τ and T as Eq. (1).

$$\tau = \frac{Tc}{J} \quad (1)$$

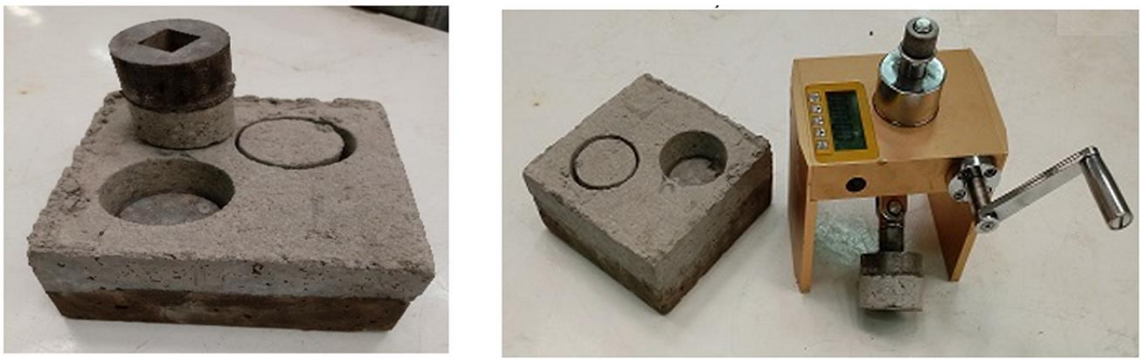
Where c is the core semidiameter (mm), J is the second moment of area (mm^4), τ is the shear stress and T is the torsional anchor. Eq. (1) has been calculated according to the Mechanics of Materials; Beer & Johnston book, assuming a linear elastic behavior. The J value is equal to Eq. (2).

$$J = \frac{\pi r^4}{2} \quad (2)$$

To measure the tensile adhesion by using the pull off test, a core with a diameter of 5 cm is drilled into the concrete. Then, a steel cylinder with a diameter of 5 cm is attached and pulled by a machine until it fractures, see Fig 4b. The tensile stress on the contact area between the layers is obtained as Eq. (3).

$$\tau = \frac{N}{A} \quad (3)$$

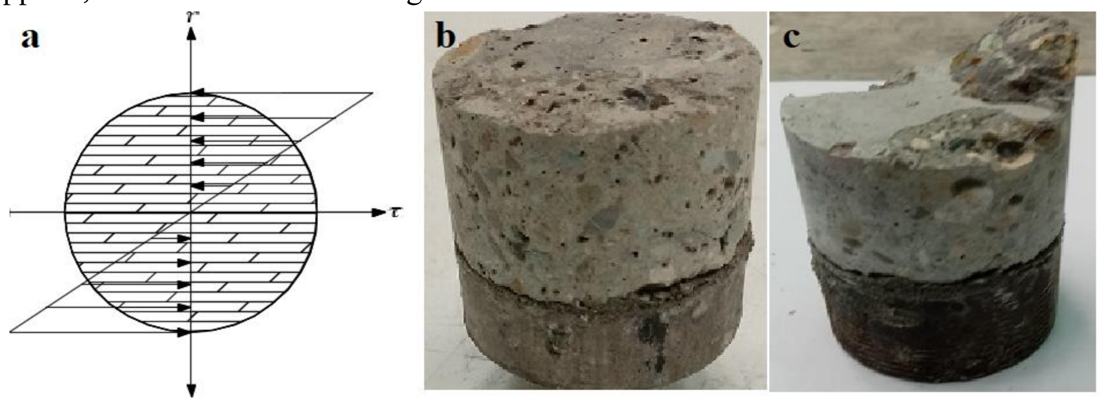
Where N is the tension load (N), A is the Cross section (mm^2).



a) Twist off method **b) Pull off method**

Fig 4. Assess the adhesion strength

As depicted in Fig. 4a, the core of this test is a shaft with a circular cross-section. As shown in Fig. 5a, when the twisting anchor is applied, the circle's surroundings with the furthest space from the center will experience the greatest shear stresses.



a) Max shear stress **b) fracture at common boundary** **c) Composite fracture**

Fig 5. Stress and fracture generation during the twist-off test

The fracture between surfaces can take several forms: it can occur at the common boundary between the substrate concrete and the mortar (Fig. 5b), it can arise within the substrate concrete or mortar, or it can take a combination of both forms (Fig. 5c). As the maximum stress occurs at the farthest space from the center of a composite fracture, Fig. 5c demonstrates that the fracture did not occur in the center but at the farthest space from the center. ASTM C109 standard [29] was used to assess the materials compressive strength.

3. Results and Discussion

3.1. The effect of pre-compression on the bond strength of repair mortars

This section evaluates the effect of pre-compression on the tensile and shear adhesion of the mortar on the concrete substrate. First, repair mortars were applied to the substrate. Following that, the mortar was subjected to various pressures for 24 hours. Pressures of 0.1, 0.5, 5, and 10 kgf/cm^2 were used in this regard. In other words, the mortars were loaded with approximately 25, 100, 1100, and 2250 kg of weight, respectively. Weights of 25 and 100 kg were manually applied to the mortars, while the concrete compression testing machine applied 1100 and 2250 kg weights. The mortars were submerged in water for 7 days before being placed in an open space until testing. The tests were conducted at 7, 42, and 90 days.

Shear adhesion from the twist-off method

Fig. 6 demonstrates that adding 0.1 kg/cm^2 of pre-compress to the mortar increased the shear adhesion between the mortar and the substrate, resulting in the twist-off method being used at various ages. However, there is no significant increase in shear bond strength. Shear adhesion was 3.96, 2.92, and 2.33 MPa after 7, 42, and 90 days, respectively, for the standard mortar. Furthermore, these strengths are 4.07, 3.09, and 2.5 MPa, respectively, for pre-compress mortar 0.1 kgf/cm^2 at the indicated ages. Thus, applying 0.1 kg/cm^2 increases shear adhesion by 2.8, 5.8, and 7.2%, respectively, after 7, 42, and 90 days.

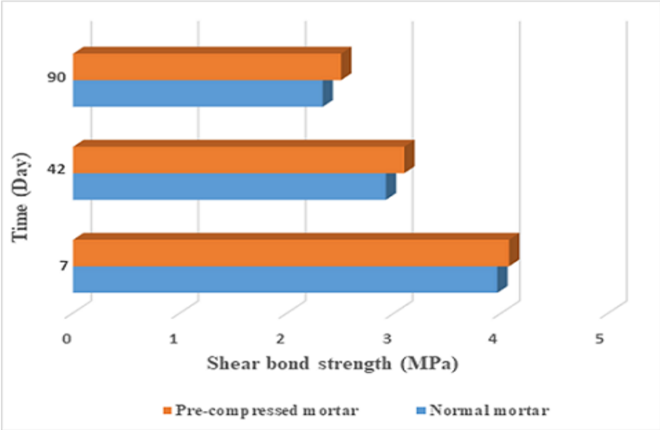


Fig. 6. 0.1 kg/cm^2 pre-compress- Twist off

Fig. 7 demonstrates that adding 0.5 kg/cm^2 of pre-compress to the mortar increased the shear adhesion between the mortar and the substrate, resulting in the twist-off method being used at various ages.

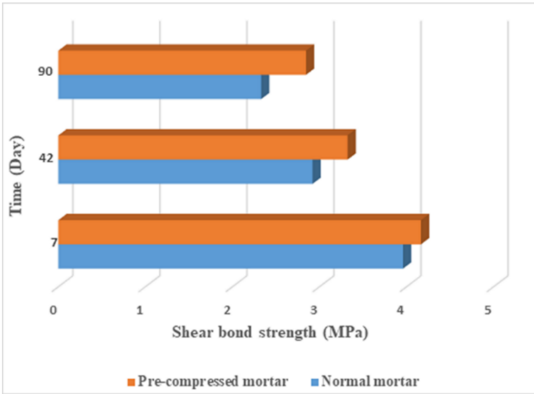


Fig. 7. 0.5 kg/cm^2 pre-compress- Twist off

Shear adhesion at the ages of 7, 42, and 90 days for normal mortar is 3.96, 2.92, and 2.33 MPa, respectively. Besides, for pre-compress mortar 0.5 kg/cm^2 at the mentioned ages, these strengths are 4.16, 3.32, and 2.84 MPa, respectively. Therefore, applying 0.5 kgf/cm^2 increases the shear adhesion at the ages of 7, 42, and 90 days by 5, 13.7, and 21.9%, respectively.

Tensile adhesion from the pull off method

Fig. 8 demonstrates that adding 0.1 kg/cm^2 of pre-compress to the mortar increased the tensile adhesion between the mortar and the substrate, resulting in the pull -off method being used at various ages. However, there is no significant increase in tensile bond strength. tensile adhesion was 1.64, 1.25 and 0.89 MPa after 7, 42, and 90 days, respectively, for the standard mortar. Furthermore, these strengths are 1.7, 1.31 and 0.94 MPa, respectively, for pre-compress mortar 0.1 kgf/cm^2 at the indicated ages. Thus, applying 0.1 kg/cm^2 increases tensile adhesion by 3.6, 4.8 and 5.6%, respectively, after 7, 42, and 90 days.

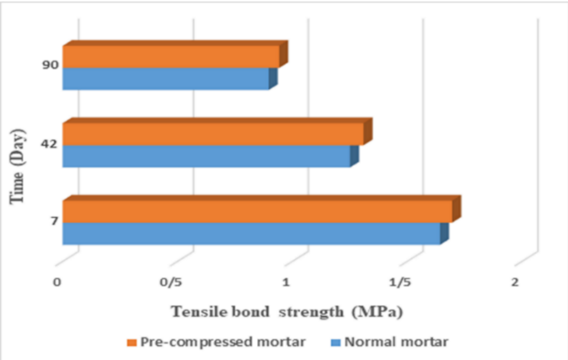


Fig. 8. 0.1 kg/cm^2 pre-compress- Pull off

Fig. 9 demonstrates that adding 0.5 kg/cm^2 of pre-compress to the mortar increased the tensile adhesion between the mortar and the substrate, resulting in the pull -off method being used at various ages.

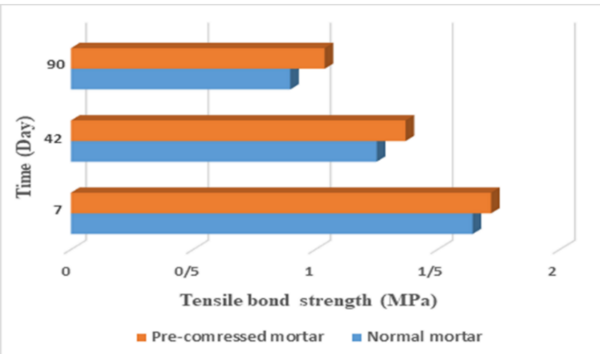


Fig. 9. 0.5 kg/cm^2 pre-compress- Pull off

However, the increase in tensile bond strength is not significant. Tensile adhesion at the ages of 7, 42, and 90 days for normal mortar is 1.64, 1.25, and 0.89 MPa, respectively. Besides, for pre-compress mortar 0.1 kg/cm^2 at the mentioned ages, these strengths are 1.72, 1.37, and 1.04 MPa, respectively. Therefore, applying 0.1 kg/cm^2 increases the tensile adhesion at the ages of 7, 42, and 90 days by 4.9, 9.6, and 16.9%, respectively.

The effect of compaction on the reduction of mortar cavities was investigated using SEM imaging (Fig. 10).

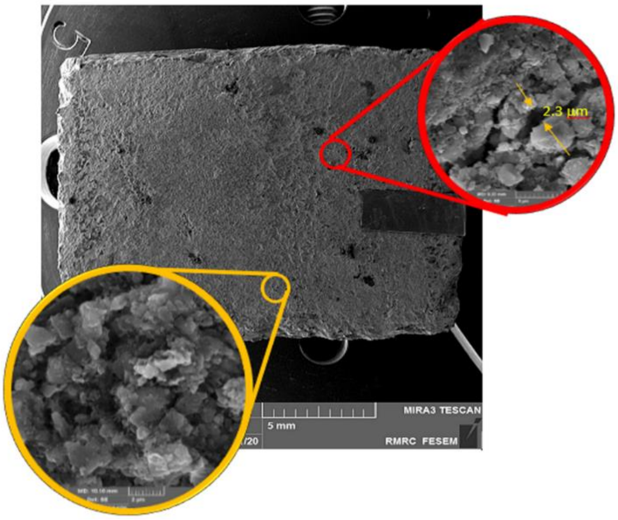


Fig 10. Microscopic image of the mortar

Micro-cavities are visible on the mortar, as depicted in this figure. These are affected by poor compaction, water evaporation, and shrinkage of concrete and mortar. The presence of such cracks can degrade the composite's physical and mechanical properties. Numerous and sizable cracks can be seen in the magnified image of the mortar due to the material's structure. The crack width was determined to be approximately 2.3 micrometers using the Image J software. These microcracks in the mortar structure can cause stress concentration, impairing the system's physical and mechanical properties. Moreover, the magnified image of the joint surface area demonstrates numerous cavities. These porosities, combined with an insufficient mixing of the mortar and concrete, could be considered the primary factor affecting the bond strength in this sample.

The theory of physical absorption is one of the most prevalent bond strength theories. Based on intermolecular polar and hydrogen forces, this theory is critical for the bond strength between mortar and concrete. According to this theory, a stronger bond is obtained when the desired surface is adequately moistened and the bond adhesive, in this case, the cement paste, reaches all areas of the surface. Thus, for the moisturizing process to be more effective, the adhesive must have a lower surface tension force than the material's critical surface tension. As a result, the bond adhesive can be spread more easily across the material's surface, and the adhesive will flow into the cavities and gaps in the surface layer.

The most ideal dispersion of the bond adhesive (the cement paste in this case) on the surface on the solid material (the surface of the concrete substrate in this case) is determined by the contact angle criterion [30]. This criterion has been indicated in Fig 11

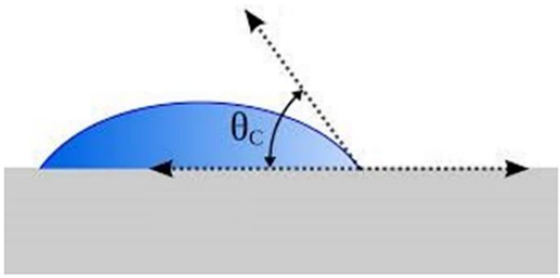


Fig 11. Liquid and solid contact angles [30]

The smaller the θ angle is, the lower the surface tension of the liquid will be compared to the solid surface. In other words, liquid has a higher tendency to flow on the surface of the solid. This concept is more evident in Fig 12.

Based on Fig 12, the middle liquid has a smaller contact angle, and thus, can provide better surface moisturizing and create a better bond strength. In terms of the concept of contact angle, it can be recognized that the less viscous the cement mortar is, the lower its surface tension, and the more fluid it is, the better it moisturizes the surface of the concrete substrate. This ultimately enhances the bond strength. Accurate measurement of the contact angle parameter, and consequently, the physical adsorption is not possible as a result of the heterogeneity and porosity of the mortar and concrete. Thus, no definitive comments can be made. As observed, applying pre-compress on the repair mortar that has not yet hardened increases the adhesion among the mortar/concrete surface. One of the reasons for this is due to higher density and greater contact area of the repair mortar components with the concrete surface.

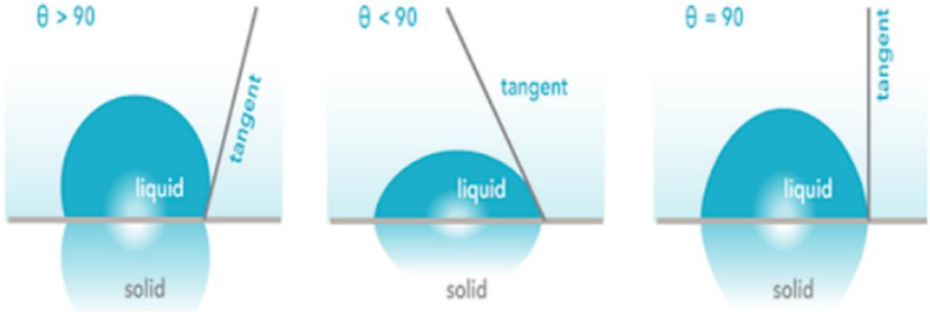


Fig 12. Contact angle and liquid broadening [30]

Comparing the pull-off and twist-off test results

Fig. 13 illustrates the relationship between shear adhesion as determined by the twist-off test and tensile adhesion through the pull-off test for the materials examined in this study.

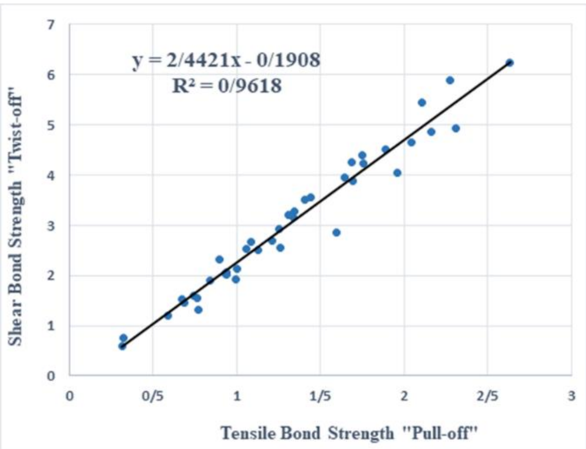


Fig 13. revelance the pull off and twist-off methods (MPa)

According to Fig. 13, the determining factor for in-situ tests was 0.961. The correlation coefficient between the tests mentioned above was 0.97. According to the excellent correlation between the in-situ tests, it is possible to obtain adhesion between the repair materials and the substrate using a relatively inexpensive and simple twist-off device rather than a more expensive pull-off device.

3.2. Mortars' in-situ strength

Table 3 contains the results of compressive strength and on-site tests on 1-2-0.4 mortar.

Table 3. In-situ and compressive strength for 1-2-0.4 samples (M1) (MPa)

tests	7-Days		28-Days		42-Days		90-Days	
	W	Open space	W	Open space	W	Open space	W	Open space
Twist-off	5.99	3.87	7.98	4.96	8.64	5.54	9.28	5.85
Pull-off	2.08	1.37	2.65	1.72	3.28	2.05	3.65	2.15
Compressive strength	40.6	24.8	56.2	33.7	61	36.2	64.7	37.6

The compressive strength of samples in open space was significantly less than that of samples in water, as demonstrated in Table 3. Because curing does not remove any moisture from the mortar, it effectively completes the hydration process of the cement. Compressive strength was 72% higher in water-cured samples than in open-space samples after 90 days. Compressive strengths of 7, 28, and 42 days samples were 64%, 67%, and 69%, respectively, greater than open-space samples.

Other studies found that 28 days increased the strength of repair mortars by 37%

compared to 7 days [31]. In another study, the compressive strength of mortars after 28 days was 54% greater than after 7 days [32]. Almost identical results were obtained in this study.

Table 4 contains the results of compressive strength and on-site tests on 1-2-0.5 mortar. As in the previous mortar, here we see an increase in compressive strength of cured samples compared to open space samples.

Table 4. In-situ and compressive strength for 1-2-0.5 samples (M2) (MPa)

	7-Days		28-Days		42-Days		90-Days	
tests	W	Open space	W	Open space	W	Open space	W	Open space
Twist-off	6.04	3.77	7.58	4.75	8.25	5.3	9.18	5.76
Pull-off	1.77	1.19	2.29	1.49	2.82	1.76	3.17	1.88
Compressive strength	34.1	20.9	47.6	28.6	51.2	30.9	54.4	32.1

Fig 14 demonstrate the relation between the twist off test and the compressive strength of specimens. According to Fig. 14, there is a strong correlation between the twist-off test and the specimen strength (R2 = 93.6% and R = 96.7%). Due to the high correlation coefficient between the results, we can use the twist-off method to determine the compressive strength of samples using the equation y=6.818x-1.86. In other research, a correlation factor of 95.1% was observed between the twist-off test and the compressive strength of concrete specimens of various strengths [17].

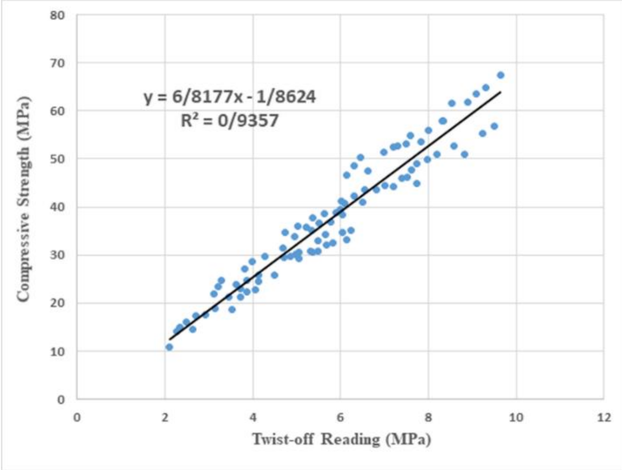


Fig 14. Twist-off and compressive strength relationship

Fig 15 demonstrate the relation of the compressive strength – pull-off method. In this section, as in the previous section, there is a great factor of determination to the consequences. The equation y=17.71x-1.69 (R2 = 94.8% and R = 97.1%) is exist between the in situ method and compressive strength.

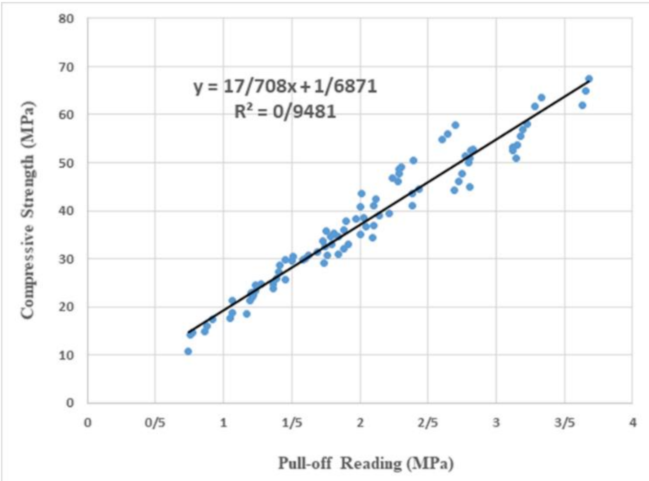


Fig 15. Pull-off and compressive strength relationship

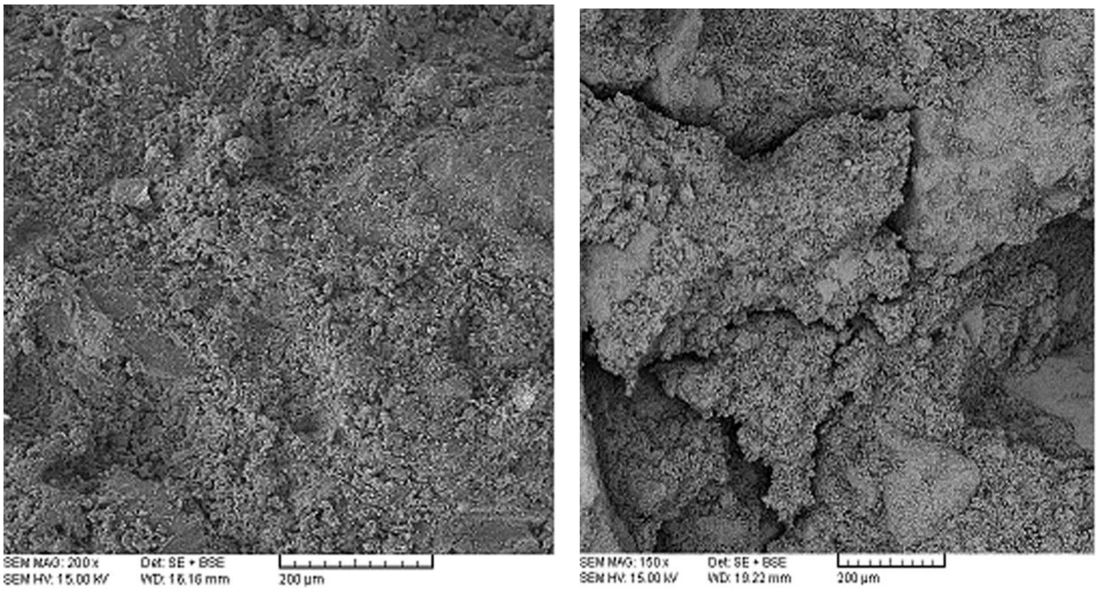
The Effect of W/C Ratio on Mortar

According to Tables 3 to 4 which are related to the compressive, it is seen that the mortar with less ratio of w/c (M1) has a greater strength with respect to the mortar specimen M2. The flexural, tensile and compressive strengths of mortar M1 are 23, 17 and 19% more than of mortar M2. Also the cement to water ratio has the same effect on the consequences of pull off and twist off test. Concerning mortar M2 which contains more water, it is seen that during hardening some water remains within it which is entrapped and gradually evaporated and leaving some cavities in the specimens which cause reduced resistance of the mortar. The ratio of w/c is straightly adequate to the diameter of pores and their number within the concrete and their increase causes reduction in the compressive strength [25,33].

Another study discovered an inverse relationship between the W/C ratio and mortar tensile strength [24]. Additionally, a further study observed a direct relationship between W/C and the mortar’s internal porosity [25].

SEM was used to analyze the results accurately to determine the effect of the curing process on repair mortars. Ettringite crystals (hydrous calcium aluminum sulfate) initially form during the cement hydration process. Then, the empty spaces are filled with prismatic crystals of CaH and fine crystals of rate. After a few days, the ettringite crystals become unstable and transform into hexagonal plates of hydrated mono sulfate, depending on Portland cement’s aluminum oxide to sulfate ratio. Additionally, hexagonal plates of hydrated calcium hydroxide were present.

Because hydrated cement contains capillary pores, amounts of water exist inside these pores. Indeed, losing the water that exists inside the pores does not cause shrinkage, but as soon as the water in the capillary pores is lost, it causes the adsorbed water loss, and thus shrinkage has resulted. To present the mortars' inside cracks after leaving the curing process, the mortars were imaged using a scanning electron microscope. In Fig 16, the mortar in the water curing and the mortar in the open space have been shown, respectively. It is observed that while the mortar is being cured, no shrinkage has occurred, and the mortar has not cracked. However, the mortar that has been in the open space for some durations has shrinkage due to the reasons of the outflow of water from its capillary pores and the loss of adsorbed water, which consequences in the development of cracks intrant the repair mortar.



a) Water curing b) Open space

Fig 16. Effect of curing on mortar shrinkage

3.3. Modeling of pull off and twist off test

In ABAQUS software, a wide variety of materials' non-elastic behavioral characteristics are available for application in various situations. This robust software thoroughly describes the non-elastic behavioral characteristics of concrete. The CDP[5] model is one of the models available in the ABAQUS software for cement material and is used in this research section. CDP is a powerful model that can be applied to various loading conditions and more realistically represents the behavior of concrete by expressing different compressive and tensile concrete treatments. According to the concrete damaged plasticity theory, the hardening variables control the completion of the broken surface, which are related to the brake mechanisms under compressive and tensile loads, respectively.

In describing the treatment of cement material after being cracked under the tensile, based on ABAQUS default, the value of compressive hardness decrease of w_c factor was considered as 1. In contrast, the value of wt coefficient was set to zero to neglect the reduction of tensile hardening. First, modeling the components of pull-off and twist-off tests were carried out, such as adhesives, 150 mm sample cube of concrete, and metal cylinders. The Create Part command was applied in the software. Module Property section and Create Material command were used to present the materials and the stress strain curve and the necessaried values. The meshing and assembling of parts were also performed with the instructions in the software. To define the supports in the twist-off test, since in the experimental, concrete samples were put in a steel frame surrounding the concrete by below to a 30 mm height, thus in modeling, supports were defined in accordance with Fig 17a. Within the pull-off method, since the machine is

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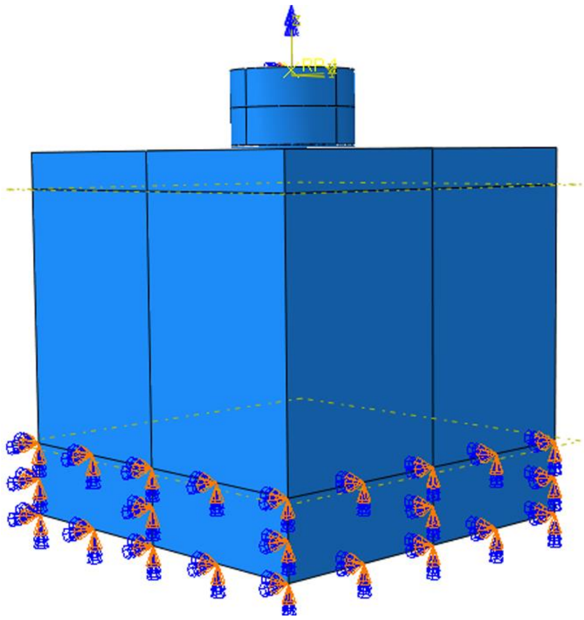
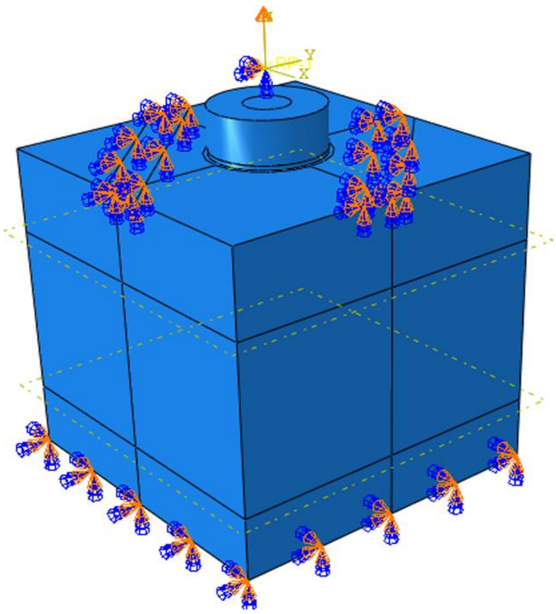
mounted on the sample, in the software, in order to define support in accordance to Fig 17b, two diagonal strips are partitioned on the surface of model.



a) Twist off test



b) Pull off test

Fig 17. Boundary conditions

Convergence the important thing in meshing samples. consequences obtained from resolving a subject in the limited element method always depend on the scale of the elements and the scale of the meshes used. However, the mesh size improvement should be done in a way that does not significantly increase the computational volume. Due to the dependency of the limited element solutions on the mesh scale, the mesh convergence should ever be checked in regions where the amounts of parameter to be exactly computed. In the twist off method, the elements in the material piece are modeled as a composition of the two C3D4 and C3D8R elements. The main part of concrete piece, which is under compress or tension, was defined using an cubic 8-node element with decreased C3D8R integrals. The element size in this part was considered 0.5 mm, being selected after convergence between 2, 1, and 0.5 mm sizes. The side parts were elementally aligned with a 4-node tetragonal with a max size of 15mm at the edges and a minimum size of 1mm at p;aces attached to the main elements (Fig 18).

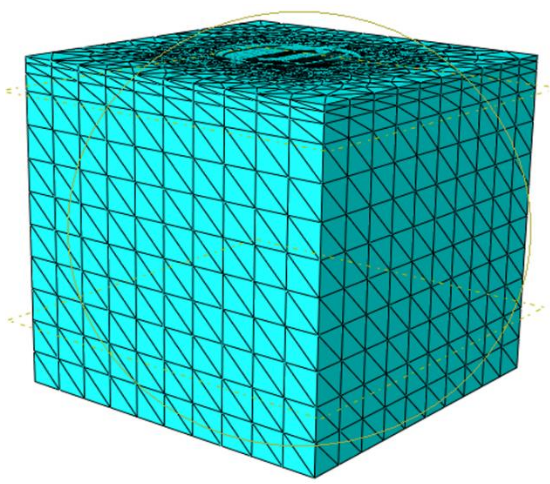
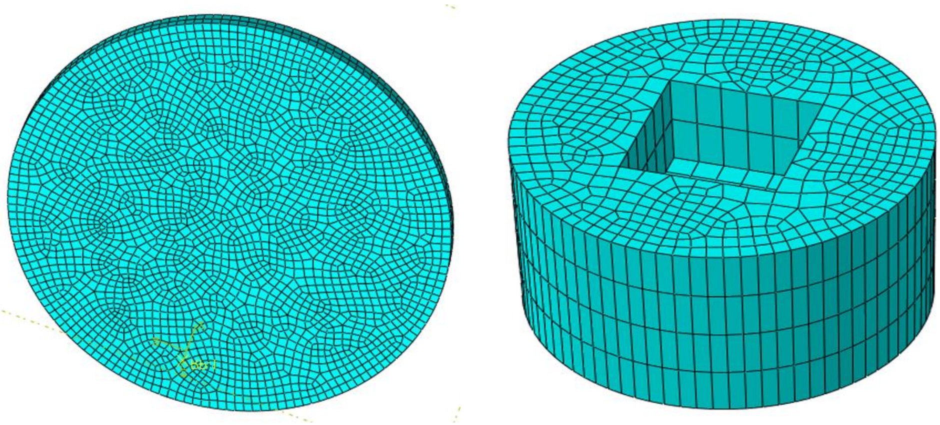


Fig 18. Meshing mortar samples in twist-off test

The adhesive piece was also partitioned with a C3D8R 1mm. The steel piece was also partitioned with an overall element size of 2mm, and the elements were taken along the 10mm axis (Fig 19).



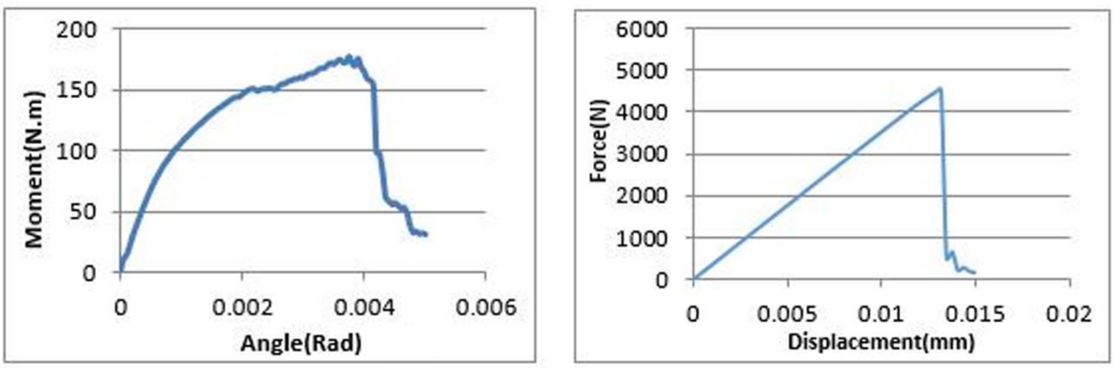
a) Meshing of adhesive **b) Meshing of steel cylinder**

Fig 19. Meshing of adhesive and steel cylinder

In the pull off metod, the element is modeled as a composition of two C3D4 and C3D8R elements. The basic part of the piece being twisted or pulled off was specified using an 8-node element with decreased C3D8R integrals. Element size in this section was considered 1mm, being choosed after convergence among sizes 2, 1 and 0.5 mm. The side parts were elementally aligned with a tetragonal 4-node with a max scale of 15mm on the edges and a minimum scale of 1mm on the places attached to the basic elements. The resin was also molded with a 2mm C3D8R type and a piece of steel with a 2mm element. Elements of steel were considered to be 10mm.

The sample tested in the experimental was created with a 47.6Mpa of cube compressive strength which failed in the twist off method at a tensile anchor of 186 N.m (7.58 MPa) and at the “Pull-off” test at 4500 N (2.29 MPa).

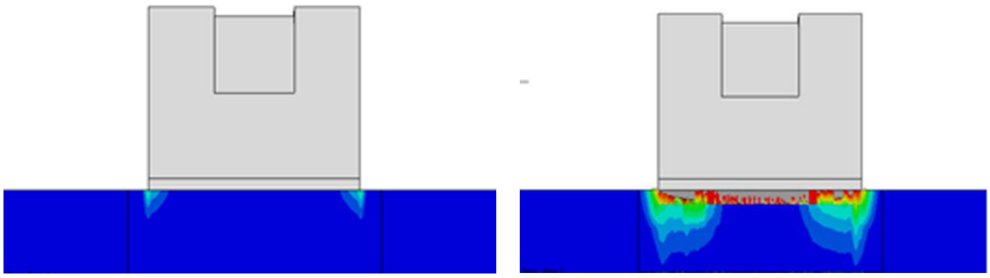
The value of the twist anchor over the twist off steel against its rotation value is shown in Figure 20a. It can be shown that the value of ultimate anchor is 177.5 N.m, which is in good agreement with the experimental value of this very sample, which is 186 N.m. Also, as is obvious in Fig 20b, in pull-off test, fracture in tensile force occurs at 4555 N, which is in good agreement with the experimental value of 4500 N.



a)Twist off loading **b)Pull off loading**

Fig 20. Developing a model for sample loading

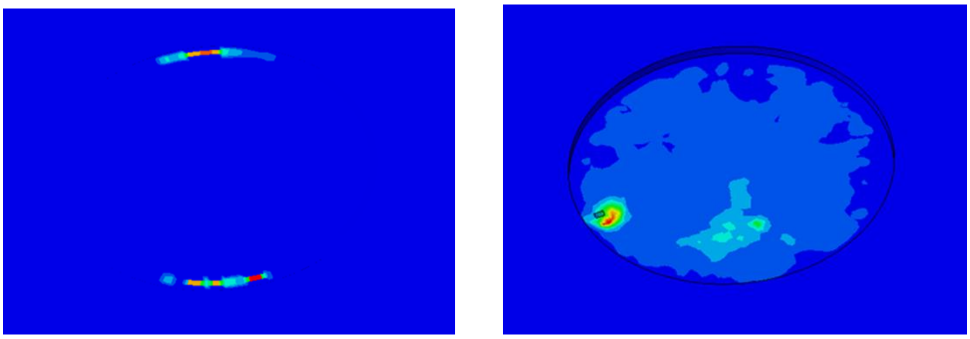
In the twist off method, the max anchor that the sample can tolerate is 178 N.m. The initial cracks in the sample start at a anchor of 50 N.m along the sample sides which are under maximum moment. The first failures in the sample happened at the anchor of 126 N.m at the edges of the sample. From this force onwards, the anchor of the incline goes much softer and the resistance of the piece becomes somewhat lower and the cracks start to greaten. This continues than the power attaines 177N.m. In this anchor, some all parts of the edge are damaged and the crack begins to grow toward the center. With an increase in force from up to 177.5 N.m, the breakdown extends substantially and the process force experiences a steep slope due to the reduction in area. Most of the failure is due to tensile failure, and at a few small points, the compressive failure occurs, which is not far significant. This happens in little regions behind the tensile cracks are interconnected (Fig 21).



a) The moment when cracking starts **b) The moment of failure**

Fig 21. Cracking and failure in twist off method

At 2448 N, the primary cracks in the pull-off method began at the sides of the cylinder to the mortar. At 3814 N, the cracking force has increased significantly. Finally, at 4555 N, the model reaches the critical force, at which point crack growth accelerates and force decreases, resulting in total damage to the sample (Fig. 22).



a) The moment when cracking starts **b) The moment of failure**

Fig 22. Cracking and failure in the pull-off test

4. Conclusion

In this study, while using the new twist-off test, the results of twist-off and pull-off tests have been compared. Also, using the abovementioned tests, the effects of pre-stress on cohesion and in-situ compressive strength of mortars have been investigated. The results are stated below.

- By applying 0.5 kg/cm^2 of pre-compress, the tensile and shear adhesion between the mortar and concrete layers increased by 31.4% and 36.9%, respectively, after 90 days.
- By applying 0.1 kg/cm^2 of pre-compress, the tensile and shear adhesion between the mortar and concrete layers increased by 5.8% and 8.8%, respectively, after 90 days.
- Between the twist-off method and the compressive strength of mortars, the coefficient of determination was 93.5%. The values above are equivalent to 94.8% for the pull-off method. Moreover, based on the coefficient of determination between in-situ methods and mortar compressive strength, these methods can be used to determine the mortar's strength.
- The compressive strength of the samples can be determined by substituting the in-situ methods for x in the equations $y=6.818x-1.86$ (for twist-off) and $y=17.71x-1.69$ (for pull-off).
- Following modeling pull-off and twist-off methods and non-linear analysis with ABAQUS, it was observed that non-linear analysis results were highly correlated with in-situ results, implying that a negligence difference exists between the two.
- Due to the great determination and correlation factore among the consequences of the pull off and twist off tests, it is feasible to obtain the adhesion among the substrate concrete and the mortar, with a inexpensive twist off device instead of applying an costly pull off machinery.

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