Factors affecting bond strength of RC column jackets

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Abstract The demand for using concrete jackets to strengthen or repair reinforced concrete columns has been increasing in the past few decades. Previous research work studied the effect of substrate surface treatment on the bond strength between the substrate concrete and overlay concrete. This paper presents an experimental and theoretical study on the effect of dowels and jacket stirrups on generating shear friction and, therefore, enhancing the overall bond strength between reinforced concrete columns and added reinforced concrete jackets. Grinding and hand-chiseling were adopted as surface roughening techniques as well as using a bonding agent at the interface between the substrate concrete and overlay concrete. An experimental program consisting of seven reinforced concrete cube specimens having two-side jackets and four reinforced concrete cube specimens having four-side jackets was conducted. Direct shear tests were adopted for this study as they represent the state of stresses usually exists in actual situations. It was found that increasing the substrate concrete surface roughness by hand-chiseling considerably improved the bond strength compared with grinding. The confining effect of stirrups used in four-side reinforced concrete jackets proved to be effective in enhancing the overall bond strength and could outperform the effect of dowels.

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1. Introduction

The need for rehabilitation (strengthening or repair) of existing reinforced concrete columns has significantly increased over the past few decades. The almost continuously escalating land value has created the demand for adding extra stories to existing buildings. For such cases, it is usually required to strengthen a number of columns of an existing building to increase their loading capacity to meet the extra load requirements. Also, poor quality concrete and lack of proper maintenance have led to the deterioration of reinforced concrete structures especially in coastal areas. Corrosion of reinforcement is probably the major cause of such deterioration and, in many cases, the repair work requires the use of additional reinforcement to compensate for the corroded original bars. In practice, the use of reinforced concrete jackets is one of the most commonly available techniques for strengthening and/or repairing reinforced concrete columns [1–4]. It is typically done by enlarging the original column cross section by adding a layer of concrete that is reinforced by both

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longitudinal and transverse reinforcement. Other techniques used to strengthen reinforced concrete columns include the use of steel jackets [5–8] and FRP wrapping [9–11].

For concrete jackets, part of the column load is transferred from the original column to the concrete jacket by bond at the interface between the substrate concrete and the new jacket concrete. The contribution of the concrete jacket to the carrying capacity of the strengthened column relies greatly on the quality of bond at the interface between the old and new concrete. There are several testing methods for evaluating bond strength which can be divided into several categories. The first category of tests measures the bond strength while the bond surface is under tensile stress. Pull off, direct tension, bending and splitting tests are the main types under this category, see Fig. 1a. In the splitting test, also known as the Brazilian test, a prism with circular or square cross section may be used and loaded in vertical compression along its length, while placed on its side, producing splitting horizontal tensile stresses. The second category of tests measures the bond strength while the bond surface is under shear stresses. These are called the direct shear methods and they include several layouts: L-shaped, mono-surface shear and bi-surface shear tests are among this category, Fig. 1b. The third category of tests measures the bond strength while the bond surface is under a state of combined shear and compression stresses. Slant shear tests fall under this category for which square or cylindrical prism specimens made up of two identical halves and bonded at an inclined surface are used, Fig. 1c. The specimens are tested under axial compression which produces shear and compression stresses at the interface surface. Several research works studied the effect of test method on the evaluation of bond strength [12–14]. It was concluded that the bond strength is greatly dependent on the used test method. The strength values obtained from some tests were up to eight times larger than those obtained from others. It is, therefore, important to select the type of bond test which closely represents the actual state of stress the structure is subjected to.

In common practice, enhancing bond strength is usually achieved by substrate concrete surface preparation and use of bonding agents between substrate concrete and overlay concrete. Dowels are usually used in such cases to enhance the bond strength by generating shear friction. The surface preparation is usually done by increasing the surface roughness of the substrate concrete and ensuring its cleanliness. Júlio et al. [14] studied the effect of using different techniques for surface roughening on the bond strength. The studied techniques were wire brushing, sand blasting and partial chipping using a needle gun. The adopted bond tests were pull-off test and slant shear test. They concluded that sand blasting provided the highest bond strength according to both types of tests and that pre-wetting the substrate surface didn’t have a significant effect on the resulting bond strength.

In another work, Júlio et al. [15] concluded that increasing the added concrete compressive strength improved the resulting bond strength. Abu-Tair et al. [16,17] reported that hand-chiseled surfaces had an average of 25% increase in bond strength, according to slant shear tests, over needle-gunned surfaces. They also noted that only 10% of the tested needle-gunned surfaces failed in bond which might suggest that the action of the needle gun caused damage to the substrate concrete and promoted failure just below the treated surface. Talbot et al. [18] reported that the bond between good quality shotcrete mixes and concrete surfaces prepared by hydrodemolition (water jetting) or chipping with light jackhammers followed by sand blasting was generally strong and durable. On the other hand, Grinding, chipping with jackhammers without sandblasting and sand blasting alone resulted in either lower bonding strengths or a reduction in bond strength with time.

A quantitative correlation between the surface roughness parameters and the bond strength was investigated by Santos et al. [19]. They used wire brushing and sand blasting for preparing the substrate concrete surface before adding the new concrete. Both slant shear tests and pull-off tests were used to measure the bond strength. Surface roughness parameters were obtained from the geometry of the actual substrate surface after preparation. Their study showed that the roughness parameters could be correlated with the bond strength and that such a quantitative approach in assessing surface roughness could be used instead of the qualitative approach generally adopted by codes. They suggested that parameters such as maximum peak-to-valley height, total roughness height and maximum valley depth may be used since they produced the highest coefficient of correlation. A similar approach was adopted by Abu-Tair et al. [16] in which they used the roughness gradient as a parameter for measuring the surface roughness and concluded that it was in agreement with visual observations.

The effectiveness of construction detailing of concrete jackets was studied by Vandoros and Dritsos [20]. They considered jacketed reinforced concrete columns subjected to cyclic transverse loading in addition to the axial loading. Three techniques were used for the jacket detailing: welding the ends of the

![Figure 1](https://via.placeholder.com/150)  
*Figure 1* Types of bond tests.
jacket stirrups, using dowels in addition to the welded stirrups, and using bent down bars to weld the jacket longitudinal bars to the original column longitudinal bars. They found that the bond between the original column and the concrete jacket was not good in the first two cases compared with the third case. Although the use of dowels improved the ductility of the tested specimen, loss of bond took place and extensive damage to the jacket was reported. It is worth mentioning that no surface preparation was conducted for all the specimens.

In view of the available literature, there seems to be lack of complete understanding of the exact contribution of dowels, stirrups and surface preparation techniques on the overall bond strength between substrate concrete and new concrete especially that these parameters are interrelated. The current work is aimed at studying the confining effect of the stirrups, used for concrete jackets, on the shear friction development, and consequently overall bond strength, and investigating how it compares to the effect of dowels and bonding agents. Two methods of surface preparation were considered: grinding and hand-chiseling. An experimental program was performed and a direct shear test was adopted to measure the bond strength as it simulates the state of stresses that actually exists at the interface between a reinforced concrete column and the added jacket.

2. Experimental program

Cubic reinforced concrete specimens were used to model the original reinforced concrete column segments. Although these cubic specimens did not satisfy the minimum ratio of the height to cross-sectional dimensions usually specified in design codes, it was believed that the studied bond strength would not be significantly affected by such ratio. Concrete jackets at two opposite sides were used to study the effect of surface preparation, use of a bonding agent and use of dowels on the overall bond strength. Grinding and hand-chiseling were the two techniques used for surface preparation. Two sets of specimens were made according to the adopted technique of surface preparation. Each set had three specimens. The first specimen had the jacket concrete placed against the substrate concrete surface as prepared by the relevant technique (denoted as G2/H2). The second specimen had an epoxy-based resinous bonding agent placed at the interface between the substrate concrete and the jacket concrete (denoted as G2A/H2A). The third specimen had 6 mm diameter dowels placed at the two jacket sides of each specimen to connect the substrate concrete with the jacket concrete (denoted as G2D/H2D).

Concrete jackets surrounding the original cube specimens at four sides were used to study the confining effect of the jacket stirrups on the overall bond strength. For each of the adopted two surface preparation techniques, a pair of specimens was made: one specimen with 6 mm stirrups (denoted as G4-6/H4-6) and one specimen with 8 mm stirrups (denoted as G4-8/H4-8). A reference specimen (denoted as R2) had concrete jackets at four sides used to study the confining effect of the stirrups on the shearing friction development, especially that these parameters are interrelated. The current work is aimed at studying the confining effect of the stirrups, used for concrete jackets, on the shear friction development, and consequently overall bond strength, and investigating how it compares to the effect of dowels and bonding agents. Two methods of surface preparation were considered: grinding and hand-chiseling. An experimental program was performed and a direct shear test was adopted to measure the bond strength as it simulates the state of stresses that actually exists at the interface between a reinforced concrete column and the added jacket.

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3. Test specimens

3.1. Geometry and detailing of specimens

The cubic specimens simulating the eleven column segments were all identical. They had a 150 mm × 150 mm square cross section and a height of 150 mm. The cube specimens were longitudinally reinforced using four bars of 8 mm diameter and transversely reinforced using two square stirrups of 6 mm diameter as shown in Fig. 2a. The two-side jackets were 150 mm wide × 150 mm high × 100 mm thick at each side of the original cube specimens. Each jacket was longitudinally reinforced using two bars of 8 mm diameter and transversely reinforced using two stirrups of 6 mm diameter, placed 80 mm apart, as shown in Fig. 2b. The dowels used for specimens G2D and H2D were 6 mm in diameter and 200 mm in length. One dowel was placed at each of the jacketed sides. The dowels were bent at an angle of 90° dividing its length into 150 mm and 50 mm segments. The four-side jackets were 150 mm high and 100 mm thick making an overall width of 350 mm. Each jacket was longitudinally reinforced using 12 bars of 8 mm diameter and transversely reinforced using two square stirrups: 6 mm in diameter for specimens G4-6 and H4-6 and 8 mm in diameter for specimens G4-8 and H4-8 as shown in Fig. 2c. The stirrups were placed 80 mm apart.

3.2. Substrate surface preparation

The preparation of the substrate surface was done when the cube specimens concrete was 38 weeks old. Five specimens were prepared by grinding: three of them were prepared at two opposite sides (specimens G2, G2A and G2D) and the other two specimens were prepared at four sides (specimens G4-6 and G4-8), see Fig. 3. Five other specimens were prepared by hand-chiseling: three of them were prepared at two opposite sides (specimens H2, H2A and H2D) and the other two specimens were prepared at four sides (specimens H4-6 and H4-8), see Fig. 4. One specimen was prepared by light hand-wire-brushing at two opposite sides for the reference specimen R2. The wire brushing was used to remove loose
crusts which were observed at the surfaces of the substrate concrete. Holes of 8 mm diameter and 75 mm depth were drilled through the prepared surfaces of specimens G2D and H2D to allow for placing the dowels. The dowels were fixed using a special dowel grout, see Fig. 5.

The contact area between the substrate concrete and the new concrete for each side was rectangular which had the same width as the width of the cubic specimen, 150 mm, and a pre-defined height of 100 mm. This height was set to guarantee the precision of the interface area and was defined by placing plastic sheets to shade the substrate concrete surface and avoid bond outside the predefined interface area.

The concrete used for jackets was placed 42 weeks after casting the cube specimens. The substrate concrete surfaces were wet before placing the new concrete. An epoxy-based bonding agent was used on the contact surfaces of the substrate concrete of specimens G2A and H2A.

4. Test procedure

All specimens were tested when the substrate concrete was 47 weeks old and the new jackets concrete was five weeks old. Static monotonic loading was applied using a compression machine to produce direct shear at the interface between the
cube specimens and the concrete jackets. The test setup is shown in Fig. 6. The cube strengths of the substrate concrete and jacket concrete at the date of specimens testing were 58.6 N/mm$^2$ and 47.4 N/mm$^2$ respectively, based on 150 x 150 x 150 mm$^3$ concrete cubes.

5. Results and discussion

The test ultimate loads and the corresponding bond strength for all specimens are shown in Table 2. Specimens having jackets from two sides failed in a brittle manner. Shear failure took place at the interface between the substrate concrete and the added jacket concrete which corresponded to the separation between the two layers of concrete at either of the two sides similar to the pattern as shown in Fig. 7 for specimen H2D. No cracks were observed prior to the ultimate load of these specimens.

The reference specimen R2 (light hand-wire-brushing) had a relatively low bond strength, 1.33 N/mm$^2$. Visual examination of the failure surface showed that the failure surface generally didn’t run through aggregate particles as shown in Fig. 8. The same observation was found for specimen G2 (grinding) which had a lower bond strength, 0.92 N/mm$^2$, compared to specimen R2. Specimen H2 (hand-chiseling) had higher bond strength, 1.92 N/mm$^2$ compared to specimens R2 and G2, and it was noted that the failure surface significantly ran through aggregate particles as shown in Fig. 9.

The failure surface for specimen G2A (grinding/bonding agent) ran through the interface between the bonding material and the jacket concrete, see Fig. 10. This suggested that the adhesion between the bonding material and the new concrete was weaker than the adhesion between the bonding material and the old concrete. The bond strength for specimen G2A was 0.33 N/mm$^2$ which was much weaker than specimens G2 and R2. Specimen H2A (hand-chiseling/bonding agent) had its failure surface running mainly through the interface between the bonding material and the jacket concrete, see Fig. 11, similar to specimen G2A. However, few aggregate par-

![Figure 4](image1.png) Substrate concrete surface prepared by hand-chiseling.

![Figure 5](image2.png) Dowel placement in cube specimens.

![Figure 6](image3.png) Test setup.

| Table 2 | Test results. |
|---|---|---|
| Specimen | Ultimate load (kN) | Overall bond strength (N/mm$^2$) |
| R2 | 40 | 1.33 |
| G2 | 27.5 | 0.92 |
| H2 | 57.5 | 1.92 |
| G2A | 10 | 0.33 |
| H2A | 90 | 3.00 |
| G2D | 185 | 6.17 |
| H2D | 145 | 4.83 |
| G4-6 | 380 | 6.33 |
| H4-6 | 655 | 10.92 |
| G4-8 | 335 | 5.58 |
| H4-8 | 750 | 12.50 |
particles appeared broken, within the failure surface, which were considerably less than the broken particles for specimen H2. The bond strength for specimen H2A was 3.00 N/mm² which was higher than that of specimens G2A and H2.

The behavior of specimens G2D (grinding/dowels) and H2D (hand-chiseling/dowels) was brittle, similar to all other specimens with two-side jackets, but the overall bond strength was considerably higher (6.17 N/mm² and 4.83 N/mm² for specimens G2D and H2D respectively). This significant increase in strength could be attributed to the developed shear friction. The failure surface for these two specimens could not be visually examined.

The behavior of the four specimens with four-side jackets was slightly more ductile than the behavior of specimens with two-side jackets. Vertical cracks at the sides of the jackets and diagonal cracks at the top faces of the jackets started to appear during loading and propagated as load increased up to the ultimate load for each specimen. After the specimens had been removed from the testing machine, it was noted that diagonal cracks existed at the bottom faces of the jackets similar to the pattern found at the top faces. Figs. 12–15 show the crack pattern for specimens G4-6, H4-6, G4-8 and H4-8 after failure. This crack pattern indicated the existence of ring tensile stress which was resisted by the stirrups. However, cracks were more intense for specimens prepared by hand-chiseling (H4-6 and H4-8) than they were for specimens prepared by grinding (G4-6 and G4-8). It is worth mentioning that the recorded ultimate loads for specimens prepared by hand-chiseling were considerably higher than the recorded ultimate loads for specimens prepared by grinding.

A comparative study was made to investigate the effect of each of the considered parameters on the bond strength. Using grinding for surface roughening in specimen G2 resulted in a 31% decrease in its bond strength compared to the reference specimen R2. This decrease might be attributed to the smooth surface resulting from grinding which was visually confirmed. On the other hand, the use of hand-chiseling in preparing the surface of specimen H2 resulted in a 44% increase in its bond strength compared to the reference specimen R2. This might be attributed to the rough texture of the treated surface resulting from the surface preparation technique. Comparing the effect of hand-chiseling, as a method of surface roughening, directly with the effect of grinding on the bond strength revealed that the bond strength of specimen H2 was 2.09 times the bond strength of specimen G2, see Table 3. Expanding the comparison to include all five specimens prepared by grinding and the corresponding five specimens prepared by hand-chiseling, revealed that the bond strength of the hand-chiseled specimens was in average 3.99 times the bond strength of the corresponding ground specimens.

Furthermore, expanding the comparison to include all five specimens prepared by grinding and the corresponding five specimens prepared by hand-chiseling revealed that the bond strength of specimen H2 was 2.09 times the bond strength of specimen G2, see Table 3. Expanding the comparison to include all five specimens prepared by grinding and the corresponding five specimens prepared by hand-chiseling, revealed that the bond strength of the hand-chiseled specimens was in average 3.99 times the bond strength of the corresponding ground specimens. This showed that hand-chiseling was considerably more advantageous in preparing substrate concrete than grinding as far as the bond strength was concerned.

The use of a resinous bonding material in specimen G2A reduced its bond strength by 64% compared to specimen G2. On the other hand, the bond strength of specimen H2A was 56% more than the bond strength of specimen H2. On average, the use of the bonding agent resulted in a 4% reduction in the bond strength. Such a small percentage might be considered insignificant for this type of tests. Therefore, it could be concluded, from the current study, that the use of a resinous bonding material didn’t have a significant effect on the resulting bond strength.

The use of dowels considerably improved the bond strength. The bond strength of specimens G2D and H2D was in average 4.61 times the corresponding bond strength of specimens G2 and H2. This could be attributed to the development of shear friction at the interface between the new jacket concrete and the substrate concrete.

![Figure 7](image7.png) Failure of specimen H2D.

![Figure 8](image8.png) Failure surfaces of specimen R2.
The confining effect of the stirrups on the resulting bond strength could be quantified and compared with the effect of dowels. The use of 6 mm stirrups in specimens G4-6 and H4-6 resulted in bond strength that was in average 6.28 times the bond strength of the corresponding specimens G2 and H2. Moreover, the use of 8 mm stirrups in specimens G4-8 and H4-8 resulted in bond strength that was in average 6.29 times the bond strength of the corresponding specimens G2 and H2. This showed that the confining effect of stirrups, both 6 mm and 8 mm, outweighed the effect of using the 6 mm dowels. This finding suggests that it is possible to rely on the stirrups of reinforced concrete square jackets for enhancing the bond strength between original column concrete and jacket concrete and, therefore, reducing (or eliminating) the amount of dowels usually employed for such cases. Table 3 presents a summary of the average bond strength ratios used to compare variations in bond strength due to the different parameters considered in this study.

Further research work is required to investigate the effect of the amount and detailing of stirrups on their efficiency in enhancing bond strength. Since the current work focuses on cube specimens simulating segments of square columns, more research work is required to evaluate the confining effect of stirrups in real square or rectangular columns with various aspect ratios.
6. Theoretical investigation

The shear strength at the interface between the old column concrete and the new jacket concrete was calculated using the equations proposed by the Egyptian Code for Design and Construction of Concrete Structures, ECP 203 [21], and the European Standard, Eurocode 2 [22].

6.1. ECP 203

The ECP 203 doesn’t account for the cohesion between the old concrete and the new concrete and accounts only for the shear friction developed at the interface due to the contribution of the dowels. Normal compressive stresses acting on the interface surface due to externally applied forces are also ignored. According to ECP 203, the contribution of the dowels to the shear resistance might be estimated using the following equation

\[ Q_u = \mu_f A_d (f_y / \gamma) \]  

in which \( Q_u \) is the ultimate shearing force resisted by shear friction, \( \mu_f \) is a coefficient of friction, \( A_d \) is the cross-sectional area of dowels, \( f_y \) is the dowels material yield stress and \( \gamma \) is a material strength reduction factor. Using Eq. (1), assuming \( \mu_f \)
equals 0.5 and 0.8 for the ground and hand-chiseled specimens respectively [21] and taking $c_s = 1.0$, the contribution of the dowels to the bond strength due to the developed shear friction was calculated and is presented in Table 4. For specimens with four-side jackets, the branches of stirrups perpendicular to each column surface were effectively assumed to act similar to dowels as far as the shear friction was concerned. Therefore, four branches of the stirrups used for each specimen were considered in estimating the developed shear friction at each side of the specimens using Eq. (1).

### 6.2. Eurocode 2

On the other hand, the approach adopted by the Eurocode 2, accounts for the cohesion between the old concrete and the new concrete at the interface, the compressive stresses due to external forces acting perpendicular to the interface surface and the contribution of the dowels to the shear resistance.

The overall shear resistance may be calculated using the following equation

$$ V_{Rd} = c_f^* \sigma_a + \rho f_y \mu \sin \alpha + \cos \alpha \leq 0.5 \nu f_y^* $$

where

- $V_{Rd}$ is the design shear resistance stress at the interface.
- $c$ and $\mu$ are factors that depend on the roughness of the interface ($c = 0.25$, $\mu = 0.5$ for very smooth surface and $c = 0.45$, $\mu = 0.7$ for rough surface).

\[ f_y^* \]

\[ \sigma_a \]

\[ \nu \]

\[ c_f^* \]

\[ f_y \]

\[ \rho \]

\[ \mu \]

\[ \alpha \]

\[ \nu \]

\[ f_y^* \]

\[ \sigma_a \]

\[ \nu \]

\[ c_f^* \]

\[ f_y \]

\[ \rho \]

\[ \mu \]

\[ \alpha \]

\[ \nu \]

\[ f_y^* \]

\[ \sigma_a \]

\[ \nu \]

\[ c_f^* \]

\[ f_y \]

\[ \rho \]

\[ \mu \]

\[ \alpha \]

\[ \nu \]

\[ f_y^* \]

\[ \sigma_a \]

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\[ c_f^* \]

\[ f_y \]

\[ \rho \]

\[ \mu \]

\[ \alpha \]

\[ \nu \]

\[ f_y^* \]

\[ \sigma_a \]

\[ \nu \]

\[ c_f^* \]

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\[ f_y^* \]

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\[ c_f^* \]

\[ f_y \]

\[ \rho \]

\[ \mu \]

\[ \alpha \]

\[ \nu \]

\[ f_y^* \]
v is a strength reduction factor which may be calculated as follows: $v = 0.6 \left(1 - f_{ck}/250\right)$.

For dowels that are placed perpendicular to the interface surface, the angle $\alpha$ equals 90° and Eq. (2) becomes

$$V_{Rd} = cf_{cd} + \mu_n \sigma_n + \rho f_{yd}$$

(3)

According to the adopted test setup, the external normal force $F_n$ across the interface resulted from the horizontal friction between the jacket and the testing machine base plate, see Fig. 16, and could be calculated as

$$F_n = \mu_f Q_u = \mu_n V_{Rd} A_i$$

(4)

where $\mu_n$ is the coefficient of friction between the concrete jacket and the testing machine steel base plate. The stress per unit area $\sigma_n$ caused by the external normal force across the interface could be calculated as

$$\sigma_n = F_n / A_i = \mu_n V_{Rd}$$

(5)

Substituting the value of $\sigma_n$ from Eq. (5) into Eq. (3) yields

$$V_{Rd} = cf_{cd} + \mu_n \sigma_n + \rho f_{yd}$$

(6)

This equation could be rearranged to obtain the value of $V_{Rd}$ as

$$V_{Rd} = (cf_{cd} + \rho f_{yd})/(1 - \mu_n)$$

(7)

Using Eq. (7) and considering $f_{ck} = 40$ N/mm², $f_{cd,0.85} = 2.5$ N/mm², $\mu_s = 0.55$ and $\gamma_s = 1.0$, the value of the overall bond strength was calculated and is presented in Table 4.

6.3. Discussion of theoretical results

Table 4 shows a comparison between the experimentally measured bond strength and the estimated values using the equations proposed by the ECP 203 and the Eurocode 2. For the experimental values, both the overall bond strength and the increase in bond strength due to using the dowels/stirrups are shown. The experimentally measured increase in bond strength was calculated as the difference in bond strength between the specimens with dowels/stirrups and the corresponding specimen with two-side jacket having the same surface preparation technique (G2/H2). The increase in the experimentally measured bond strength of specimen G2D, due to the use of dowels, was 5.25 N/mm² compared to specimen G2. Similarly, the increase in the experimentally measured bond strength of specimen H2D was 2.91 N/mm² compared to specimen H2. A similar approach was adopted for specimens with four-side jackets.

According to the approach adopted by the ECP 203, the bond strength of specimens without dowels/stirrups could not be estimated as the cohesion between the new concrete and the old concrete was ignored. Comparing the values of the calculated bond strength, for specimens with dowels/stirrups, with the experimentally measured values showed that the code equation considerably underestimated the contribution of the dowels to the bond strength. A similar conclusion could be drawn when the calculated values were compared with the experimentally measured increase in bond strength.

The overall bond strength estimated using the equations proposed by the Eurocode 2 was in good agreement with the experimentally measured values for specimens without dowels/stirrups, G2/H2. However, the estimated values for specimens with dowels/stirrups were significantly lower than the experimentally measured ones. This indicated that the Eurocode 2 equations were conservative in evaluating the contribution of the dowels/stirrups to the overall bond strength. However, it is worth mentioning that the values obtained using the Eurocode 2 equations were significantly higher than those obtained using the ECP 203.

7. Summary and conclusions

The effects of surface preparation and use of bonding agents on the bond strength between new concrete jackets and old substrate concrete were experimentally studied. The contributions of dowels and concrete jacket transverse reinforcement to the shear friction, and consequently on the overall bond strength, were also studied, quantified and compared. A total of eleven specimens (7 specimens having two-side jackets and 4 specimens having four-side jackets) of reinforced concrete cubes simulating column segments with concrete jackets were manufactured and experimentally tested. The equations presented by the ECP 203 and Eurocode 2 were used to calculate the overall bond strength and the results were compared with the experimentally measured values. The following conclusions could be drawn from the current study:

(1) Increasing the surface roughness of the substrate concrete by hand-chiseling is considerably more effective than grinding. The obtained bond strength for specimens treated by hand-chiseling was in average 3.19 times the obtained bond strength of specimens treated by grinding.

(2) The use of a resinous bonding agent between the substrate concrete and the new jacket concrete didn’t have a significant effect on the resulting bond strength. Furthermore, the adhesion between the bonding agent and the new concrete was found to be weaker than that between the bonding agent and the substrate concrete.

(3) The use of steel dowels to connect the new jacket concrete to the old substrate concrete significantly improved the overall bond strength due to the developed shear friction. The overall bond strength of specimens with dowels was in average 4.61 times the corresponding bond strength of specimens without dowels.

![Figure 16](image-url) Friction force at base plate.
The confining effect of jacket stirrups fully surrounding a reinforced concrete cube specimen considerably improved the overall bond strength between the substrate concrete and the jacket concrete and could outperform the effect of dowels.

Both approaches presented in the Egyptian Code for Design and Construction of Concrete Structures, ECP 203, and the European Standard, Eurocode 2, for calculating the interface bond strength were considerably conservative.

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