Journal of Advanced Engineering Trends
ISSN : 2682 - 2091

Vol.42, No.1. January2023

http://jaet.journals.ekb.eg

Factors affecting the bond strength between new and old concrete

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Abstract

One of the main concerns in repair is a sufficient bond between the substrate and the repaired material, especially for the long-term performance and durability of the structure. We carried out in this study an experimental work to investigate the effect of main parameters that primarily influence the bond between old and new concrete in dry, hot weather. The compressive strength considered for the case of old concrete is 15 MPa. While for the case of the new concrete, the considering compressive strengths as 15, 30, 40, and 50 MPa. We cast a total of 48 cube samples (10×10×10 cm) and tested them for the grade of old concrete, the new concrete as a jacket in both faces of the old one. We prepared the substrate surface by grinding. We cast the new concrete over the old concrete where four cases of the bond between old and new concrete considered included using bond agent, using dowels, using bond agent and dowels, and without using bond agents or dowels. The samples were saved in the oven at 50^0C for 28 days till the test day. Test results indicated that using new concrete with higher compressive strength slightly affected the bond between old and new concrete. While using a bond agent or dowels remarkably influenced the bond between old and new concrete and gave the same results, but using both gave maximum shear strength than other considered cases.

Keywords: *Bond Strength, Shear Strength, roughness, nails.*

1. Introduction

Most structures have reached the end of their time life or were constructed wrong without achieving the design requirements (Ramasamy et al., 2021), so repairing these buildings is essential for using these structures. Many invented repair methods are for the rehabilitation of concrete members through adding a new concrete layer to the existing concrete members.

The cohesion, the friction properties of the concrete, and the stresses act on it played a paramount role in the capacity of the interface region between the substrate and the overlay layer (Al-Fasih et al., 2021). Many factors have effects on the cohesion and friction of the interface as surface preparation and curing methods. That increases the shear strength of the interface (Abd Malek et al. 2018),(Naresh, Lavanya, and Kumar 2021) stated that the more roughness for the substrate surface you will get more bond strength at the interface (Naresh, Lavanya, and Kumar 2021). Using shear connectors for increasing the bond strength of the interface is a paramount approach. Nguyen proved that using dowels enhances the flexural strength for the interface zone, and using 0.48% for dowels is considered a suitable choice (Nguyen, Serhatoğlu, and LİVaoĞLu 2018). It is a common way used in sites for strengthening the damaged concrete. BO LI used a direct shear test to study the shear strength between the ordinary concrete and the Ferro cement. Stated that the surface preparation technique more significant than using shear connectors (Li and Lam 2018). Haber studied the consolidation of the new overlay and the substrate and stated that when good achieving consolidation, the roughness becomes less critical. While if not guaranteed, we should pay more attention to substrate roughness (Haber et al., 2018). Lopez showed that substrate roughness importance depends on the type of test for the interface on direct tensile strength. Test roughness has no role in the bonding strength because it depends on the chemical bonding agent used, push-off test, and slant shear test (López-Carreño et al., 2017). So we should know the stresses composed to the interface to face it with the suitable method (Bassam A. Tayeh) proved that the strength of the new concrete has a considerable effect on the bond strength more than the roughness in the tension tests (AL Hallaq, Tayeh, and Shihada 2017), Rith investigate the weak factors that may cause more stress on the overlay because of poor

Received: 12 July, 2021, Accepted:29 July , 2021

bonding at the interface and its results lead to that the substrate concrete conditions may cause poor bond which lead to, early stress on the overlay (Rith et al. 2016), generating shear frictions using steel dowels and improving the bond strength using different substrate roughness approaches, Elbakry performed a direct shear tests for new concrete jackets and stated that the samples with steel dowels have a greater shear strength about 4.6 than the samples without dowels and he found that using an epoxy resin did not give a remarkable difference in the shear strength at the interface and the adhesion of the epoxy resin to the old concrete is greater than the adhesion of the epoxy resin and the new concrete (Elbakry and Tarabia 2016).

The scope of our research is to investigate the influence of shear connectors and the epoxy resin and the differential stiffness of the new concrete, and the combination between them on the bonding strength at the interface, especially when curing the samples in bad conditions as dry, hot weather.

2. Experimental programs

2.1. Used materials

We used a coarse aggregate with a maximum nominal size of 15 mm for casting the new and old concrete grades, coarse-medium sand for fine aggregate, ordinary Portland cement (with cast grade of 42.5 N/mm^2), and silica fume casting the high compressive strength grades 40, 50 MPa. Table (1) shows the mixture proportions for each cast grade.

Table 2 M

Table 1 Mixture proportions

2.2. Specimens preparation

Mix componentsKg/m^3	Concrete grade MPa			
	15	**30**	**40**	**50**
Gravel	1400	1248	1173	1150
Sand	760	672	628	626
Cement	250	450	470	500
W/C	0.75	0.4	0.37	0.33
Silica	0	0	82	99.9
super plasticizer DPF	0	6.4	8.2	9.2

An ordinary cubic concrete specimen 10*10*10 cm with 15 MPa cast grade represented the old concrete repaired. Four weeks later, we demoulded the specimens, and we roughened old concrete specimen's substrate surface by grinding to achieve the same roughness. Because it is a fixed variable in this research (Fig. 1), samples with dowels prepared with a 6mm diameter steel bars with 240 MPa grade had an embedded length of 3 cm in the old concrete cubes from two sides using an epoxy agent specific for it (master flow 936 AN) (Fig. 2). The epoxy used for the interface (Master Brace ADH 1414) is a permanent epoxy adhesive for internal or external bonding of renderings, granolithic toppings, and concrete to concrete. It tolerates a degree of moisture before and during curing and is insoluble when cured. The ultimate bond strength is greater than the tensile strength of concrete. Master Brace ADH 1414 does not shrink and provides an even and stress-free bond, and its properties as shown in Table (2).

Mixed density ASTM D1475 @ 25°C	1485 kg/m³
Open time ASTM D2471	25°C 150 min 40°C 75 min
Full cure ASTM C661	7 days
Slant shearbond strengthASTM C882-99	>20 MPa
Water absorption ASTM D570	<0.1%
Compressive strength ASTMD695-91	>50 MPa

We prepared samples with an epoxy resin also as shown in (Fig. 3) and cast concrete jackets on two opposite sides of the old cubes. After 4 weeks from casting the old concrete with variable strengths 15, 30, 40, 50 MPa, the casting has been done for each strength without using nails, bonding epoxy with nails only, and nails and bonding epoxy. Test specimens for each new concrete grade as shown in (Fig. 4) (Elbakry and Tarabia 2016) with a total length of 24 cm and width of 10 cm. We cast 12 samples and lifted them for four weeks in 500C in a dry oven to achieve the hot, dry weather which we study.

Fig. 1. Surface preparation by grinding

Fig. 2. Specimen with nails

Fig. 3. Surface preparation with an epoxy

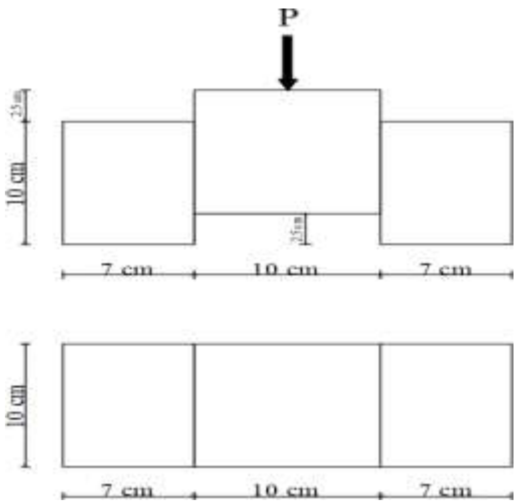

Fig. 4. Test sample dimensions

Fig. 5. Surface preparation with epoxy and nails

Fig. 6. Observing temperature and humidity in the oven

Fig. 7,8. During casting the samples

2.3. Test procedures

We performed a total of 48 cubes (10*10*10 cm) represent the old concrete (of strength 15 MPa) and 12 sets for every new concrete (strength 15 MPa). We cast three samples of old concrete (denoted as C-C15), three using epoxy (as C-CE15), three using nails only (as C-CN15), three using both nails' samples, and epoxy samples (denotes as C_CEN15). The sequences followed with the other strengths as shown in Table (3).

After taking out the specimens from the oven, we tested them (the substrate concrete eight weeks old and the new concrete jacket were four weeks old). With a compression machine test, a static loading occurs direct shear stress at the interface between old and new concrete. (Fig. 9) shows the test sample used for investigation for each case study; three specimens were loaded till failure and then get the average bond strength by MPa.

Fig. 9. Test sample

Table 3 variables abbreviations used in the test

Cases of the substrate surface preparation	**Grade of the new concrete overlay (MPa)**			
	15	**30**	**40**	**50**
Without using any agent	C-C15	C-C30	C-C40	C-C50
Using epoxy only	C-CE15	C-CE30	C-CE40	C-CE50
Using nails only	C-CN15	C-CN30	C-CN40	C-CN50
Using both of nails and epoxy	C-CEN15	C-CEN30	C-CEN40	C-CEN50

3. Results and discussion:

Table 4 shows the overall average shear stress at the interface between old and new concrete against each case of all cases in this test (16 cases). (Fig. 10) shows the shear failure at the interface between old and new concrete. We found no particle damage in the specimens cast without any bonding agents. Failed samples that had an epoxy agent the crack went throw the epoxy without any particles damage (Fig. 11). All of the specimens that had nails, show destruction with particles damage (Fig. 12). Table 4 shows increase of the interface bonding for Samples with a surface prepared by bonding agent or nails, and there is a slight increase in the bonding strength for each increase in the new overlay strength.

Fig. 10. Failure at the interface

Fig. 11. De-bonding in case of epoxy resin

Fig. 12. Failure in case of nails

Table 4 Average Overall bond strength

Average Overall bond strength (MPa)				
cases of bond between old and new concrete	**Grade of the new concrete jacket MPa**			
	15	30	40	50
C-C	1.065	1.165	1.33	1.4
C-CE	1.6	1.765	2.0	2.065
C-CN	1.33	1.665	1.8	1.93
C-CEN	2.0	2.13	2.33	2.465

Fig. 13. Interface failure without using any bonding agents

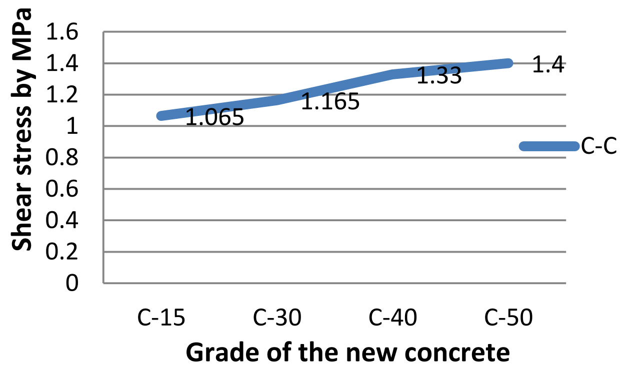

Fig. 15. Effect of the new concrete grade

Figure 14 shows Average Overall bond strength (MPa) for all cases and the correlations between them.

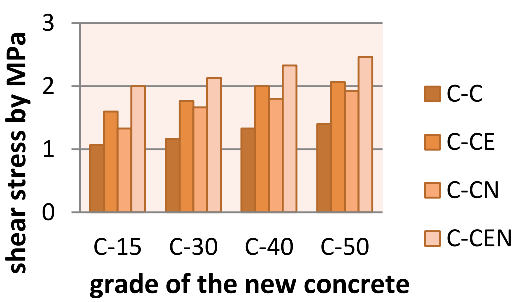

Fig. 14. Average bond strength for all cases

3.1. Effect of the new concrete strength only on the interfacial bond strength:

Figure 15 shows the effect of the new concrete grade on the bond between the new concrete and 15 MPa old concrete strength.

The test specimens cast without any adhesive agent or shear connectors, by using a higher new concrete strength, the shear bond strength increased, and the increase of the interfacial shear strength was about 9%, 24.9%, 31% when using a new concrete strength of 30, 40, 50 MPa respectively. The highest rate of the bond strength at the interface noticed when using new concrete with a strength of 30 MPa, the rate of bond increases with the increase of the new concrete strength to be 30, 40, 50 MPa is 0.67%, 1.65%, 0.7% respectively, which shows that the most effective strength of new concrete in the range between 30, 40 MPa. By using new concrete strength (50 MPa), the rate of bond strength decreases due to the brittle properties of the new concrete that leads to failure of the bond between new and old concrete.

An extremely high difference between the old concrete and the new one is not essential due to the increase in the bond strength. We can conclude that to achieve economic bond strength, the difference between new concrete strength and the old one should be 2-3 times the old concrete strength in case of no use of any adhesion agents.

3.2. Effect of the new concrete strength with using an adhesive agent on the interfacial bond strength:

Figure 16 shows the effect of the new concrete grade when using an adhesive agent on the bond between the new concrete and 15 MPa old concrete strength.

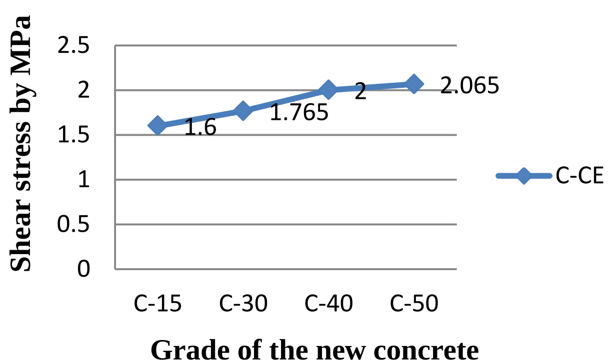

Fig. 16. Effect of the new concrete grade when using an adhesive agent

The test samples were cast with an adhesive agent (Master Brace ADH) and without shear connectors. Using a higher concrete strength, the more bond strength we got, the increasing was 10.5%, 40%, 46% for using 30, 40, 50 MPa new concrete strength respectively concerning 15 MPa as a new concrete strength jacket. We noticed the highest rate of the bond strength between 30, 40 MPa of the new concrete strength. Rates of increase of the bond strength were 1.1%, 2.35%, 0.65% for using 30, 40, 50 MPa of the new concrete strength. The very high strength difference between the new and the old concrete not necessary to enhance the interfacial bond strength. So, we can conclude that to achieve an economic and a good bond strength when using an adhesive agent in hot, dry weather, we can use a new concrete bigger than 2-3 times than the old concrete strength.

3.3 Effect of the new concrete strength when using shear connectors on the interfacial bond strength:

Figure 17 shows the effect of the new concrete grade when using shear connectors on the bond between the new concrete and 15 MPa old concrete strength.

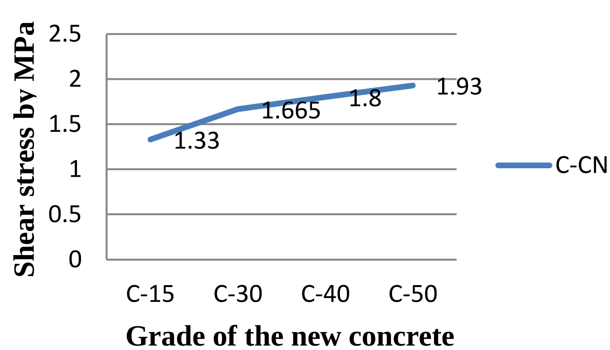

Fig. 17. Effect of the new concrete grade when using shear connectors

The test specimens were cast with shear connectors (one for each side) and without any adhesive agent. Using nails shows more bond strength at the interface when using a higher new concrete strength.

The increase in the bond strength was 25%, 35%, 60% for using a new concrete of 30, 40, and 50 MPa, respectively. Concerning the reference sample with a new jacket of concrete strength of 15 MPa, the rates of increment of bond strength were 2.25%, 1.35%, 1.3% by using new concrete of 30, 40, and 50 MPa strength, respectively.

We found the high bond strength set between 15 and 30 MPa however, the maximum increase at 50 MPa. So, if we look from an economic point of view, we can use a new concrete strength two times bigger than that of the old one at hot, dry weather curing because it gives the maximum rate of increasing the bond strength and better bonding strength with 25% more than the reference one.

Using very high concrete strength like 50 MPa shows better (60%) bonding strength because of high bonding between the steel bars with the new concrete. The high density of the new concrete used in this strength is not economical and gave a minimal increase in the bond strength concerning the used concretes in this investigation.

3.4. Effect of the new concrete strength when using shear connectors and an adhesive agent on the interfacial bond strength:

Figure 18 shows the effect of the new concrete grade when using shear connectors and an adhesive agent on the bond between the new concrete and 15 MPa old concrete strength.

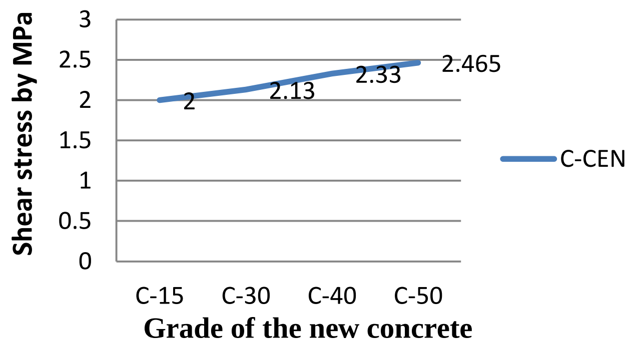

Fig. 18. Effect of the new concrete grade when using shear connectors and an adhesive agent

We cast test samples after preparing the interface surfaces with an adhesive agent (Master Brace ADH) and one shear connector for each side. Using new different concrete strengths 30, 40, 50 MPa concerning the reference sample, 15 MPa give an increment of 6.5%, 16.5%, 23.25% in bonding strength at the interface, rates of increase in bond strength for different concrete strengths were 0.9%, 2%, 1.35% for 30, 40, 50 MPa new concrete strength.

The adhesive agent has additional control on the bonding strength, in this case, because we observed that the maximum rate was between 30, 40 MPa for the new concrete overlay. The same result we got from the case of the adhesive agent only.

The conclusion that; we can use great strength 2-3 times for the overlay than the old one to get the best rate and bonding strength at the interface from an economic point of view in hot, dry weather.

3.5 Effect of using bonding agents on the bond strength at the interface in case of using the same old concrete grade in the new jacket:

Figure 19 shows the effect of using bonding agents like nails and an adhesive agent on the bond power when using the strength of the old concrete in the overlay casting.

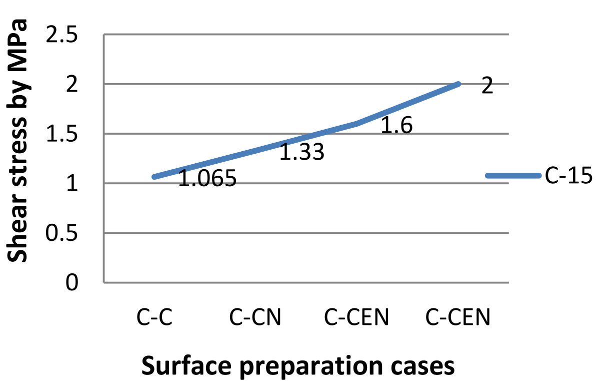

Fig. 19. New overlay with 15 MPa

Test specimens were cast with a new concrete with a grade of 15 MPa with different surface preparation cases, without any bonding agents, using nails, using an adhesive agent, and using nails and an adhesive agent. Using shear connectors and an adhesive agent with both of them enhanced the interfacial bond with 25%, 53.5%, 93.5%, respectively. Concerning the reference sample (without any bonding agents), we observed that using an adhesive agent gives more bonding strength than nails with a 20% increase of bond strength.

Using both of them gives an increment of 25% than the bond strength in using an adhesive agent only. So, we can conclude that using shear connectors and an adhesive agent gives the highest interfacial bond strength in using the same old concrete strength in the overlay in hot, dry weather.

3.6. Effect of using bonding agents on the bond strength at the interface in case of using 30 MPa strength in the new jacket:

Figure 20 shows the effect of using bonding agents like nails and an adhesive agent on the bond strength when using 30 MPa concrete strength in casting the overlay.

We cast test specimens with a new concrete jacket of 30 MPa strength with different surface preparation cases. The results showed that using nails, an adhesive

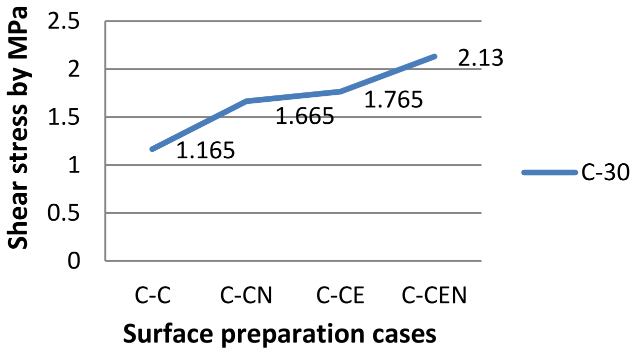

Fig. 20. New overlay with 30 MPa

agent, and both of them increased interfacial bond strength by 50%, 60%, and 96.5%, respectively. Regarding the reference sample (cast without any bonding agents), we noticed that using an adhesive agent enhances the bond strength by 6% than the bond strength when using shear connectors. Shear connectors with good new concrete strength gave the same bond strength when using an adhesive agent, which can be explained by, the quality, proper density, and flexural properties of the new concrete. When we increase its strength, using both shear connectors and an adhesive agent, the bond strength increased by 21% more than using an adhesive agent only. So, we can use both bonding agents to get the maximum bond strength at the interface in case of using it two times the old concrete strength in hot, dry weather.

3.7. Effect of using bonding agents on the bond strength at the interface in case of using 40 MPa strength in the new jacket:

Figure 21 shows the effect of using bonding agents like nails and an adhesive agent on the bond strength when using 40 MPa concrete strength in casting the overlay.

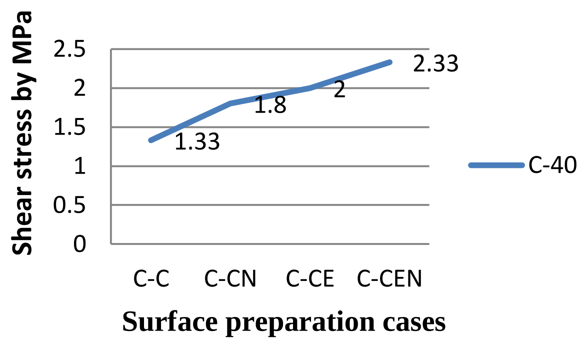

Fig. 21. New overlay with 40 MPa

We cast the new concrete samples using 40 MPa concrete strength containing silica fume to get high strength with more density concrete, with different surface preparation cases. The results showed that using nails, adhesive agents, and both together gave more bond strength by 35%, 50%, and 75%, respectively than reference samples (cast without any bonding agents). Using an adhesive agent causes an increment by 11% in bond strength than using nails only, and both gave an increment by 16.5% than using an adhesive agent only. The increase in bond strength in this state is not high like the previous states is due to the overlay strength that provides a perfect interfacial bond for the reference sample (cast without any bonding agents), compared with the state (15, 30 MPa) of concrete strengths. The increment of bond strength, as we mentioned before, shows that using both shear connectors and an adhesive agent gives the highest bond strength in the case of casting a new concrete with about 2.5 times than the old concrete strength in hot, dry weather.

3.8. Effect of using bonding agents on the bond strength at the interface in case of using 40 MPa strength in the new jacket:

Figure 22 shows the effect of using bonding agents like nails and an adhesive agent on the bond strength when using 40 MPa concrete strength in casting the overlay. We cast test specimens with a new concrete strength of 50 MPa with different surface preparation cases. The increase of bond strength was 38%, 47.5%, and 76% using nails, an adhesive agent, and both of them respectively for the reference sample. This state is like the last one (using 40MPa) because both represent a high strength concrete state and each of them contains silica fume so, the properties are mostly the same. We can notice that the increment of bond strength was 7% when using an adhesive agent than using nails only and was 19% when using both of them than using an adhesive agent only and the results are close to the results of the last state. So, we recommend that using both bonding agents in case of using a new concrete with a strength higher than 3.5 times than the old concrete in hot, dry weather to get the maximum bond strength.

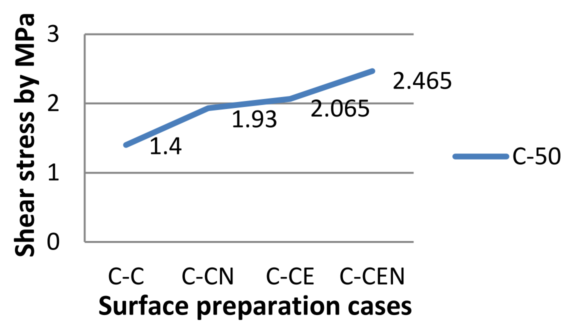

Fig. 22. New overlay with 50 MPa

3.9. Relative interfacial bond strength using different techniques:

Table 5 shows the relative bond strength at the interface with respect to the original case (casting the same grade for the old concrete as a new one without using any bonding agents). The results show that using high concrete strength 50 MPa with an adhesive agent and shear connectors gives maximum bond strength with a relative percentage of 231% from the original case, for the same surface preparations using a new concrete with a strength 40 MPa gives 219% relative bond strength and using a new concrete with 30 MPa strength gives 200% relative bond strength from the original case, so it is obvious that surface preparations using bonding agents have a greater impaction on the bond strength than using a higher concrete strength and it has a lower cost than using a very high concrete strength. From results using a new concrete has a double value than the old one with using bonding agents is the best way to have good and economic bond strength.

Table 5 Relative bond strength

Used techniques	Relative bond strength %	Used techniques	Relative bond strength %
C-C15	100	C-C40	125
C-CE15	150	C-CE40	188
C-CN15	125	C-CN40	169
C-CEN15	188	C-CEN40	219
C-C30	110	C-C50	131
C-CE30	166	C-CE50	194
C-CN30	156	C-CN50	181
C-CEN30	200	C-CEN50	231

4. Conclusion

The study shows that the 'push-off test' investigating the bond between new and old concrete without confining the specimen. A slight increase of the bond strength for using high grade of the new concrete and using nails or epoxy resin for bonding gives the same results for the high grades concrete, and the bonding strength in case of using both of them increases the bonding strength compared to using one of them. More investigations about bonding strength recommended, changing the curing method and using lower compressive strength of the new concrete using different surface preparation techniques and then compare with the given results.

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