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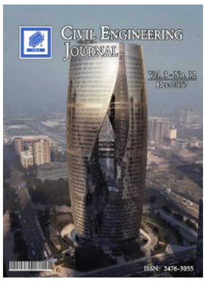

Experimental Study on Bond Stress between Ultra High Performance Concrete and Steel Reinforcement

Ahad Amini Pishro [a*], Xiong Feng [a]

[a] *Western China Earthquake and Hazards Mitigation Research Center, College of Architecture and Environment, Sichuan University, China.*

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Abstract

Due to axial deformations generally caused by flexure, shear stress will be generated across the interface between reinforcement and surrounding concrete. This longitudinal shear stress is called bond stress and coordinates deformation between concrete and reinforcement. With increasing a member's axial deformation, bond stress finally reaches its ultimate value, bond strength, after which deformation of reinforcement and surrounding concrete will be not coordinated any more. Studies have shown that addition of nanosilica into cement-based materials improves their mechanical properties. Considering the unique characteristics of nanosilica, it seems that this material can be used in ultra-high performance concrete. Therefore, further research is needed on how to use it in concrete mixes. Due to the importance of examining bond stress and the lack of exact equations for bond stress of ultra-high performance concrete and steel reinforcement, the present study aimed to assess the bond stress between concrete and steel reinforcement.

Keywords: Bond Stress; Ultra-High Performance Concrete; Steel Reinforcement; Nanosilica.

1. Introduction

High strength and ultra-high performance concrete has many advantages. Due to its better mechanical properties and low permeability, this type of concrete is gradually replacing conventional concrete. Because of its considerable properties, this type of concrete can either be used in structures to resist loads, or in large bridges and several constructions due to being affected by environmental conditions. Micro-silica is widely used as an additive to cement in producing high performance concrete. This matter is used to enhance the strength and efficiency of concrete. Several experiments have shown that replacing part of cement with micro-silica improves sulphate and acid resistance of concrete and reduces chlorine permeability. By addition of microsilica to concrete or cement mortar, due to being fine grained, it fills the space between cement particles, so the existing pores will become smaller. Moreover, due to the reaction between silica and calcium hydroxide remained from cement hydration process, more C-S-H gels are produced and, as a result, more capillary cracks will be covered [1]. Recently, considering the unique characteristics of nanosilica, it seems that this material can be used in ultra-high performance concrete. Therefore, further research is needed on how to use it in concrete mixes. To this end, the present study used Pullout test to assess the effect of nanosilica on the bond stress between steel reinforcement and ultra-high performance concrete. Pullout test is the oldest, simplest, cheapest and less time-consuming way to measure local bond stress of concrete. In this test, a reinforcement is placed into a cylindrical or cube shaped concrete specimen, and then while the concrete is fixed in place, the reinforcement is pulled out. Since the reinforcement is under tension and concrete is under compression, the resultant relative strain will lead to relative slip. Many researchers have studied the bond between streel reinforcement and ultra-high performance concrete. Alkaysi, M., El-Tawil, S. (2016) conducted an experimental study on the bond stress between ultra-high performance concrete and streel reinforcement. They calculated the bond stress between 13, 16 and 19 mm reinforcements and ultra-high

* Corresponding author: ahad.aminipishro@yahoo.com

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performance concrete in the pull out test. The average compressive strength of the ultra-high performance concrete made in these experiments was 190 MPa [2]. Carbonell Munoz, M.A. et. al. (2014) examined the bond stress between conventional and ultra-high performance concrete and streel reinforcement. The conventional concrete with a compressive strength of about 50 MPa and the ultra-high performance concrete with a compressive strength of about 150 MPa were made for these experiments [3]. Engstrom, B. et. al. (1998) presented the effects of concrete confinement and coating on bonding in high strength concretes. They showed that with reducing thickness of coating up to 16 mm (equal to the diameter of reinforcement) resulted in a 25% reduction in the maximum bond stress compared with the well-confined specimen (with sufficient coating). When using a 32 mm coating, the loading will be same as that of well-confined concrete [4]. Kim, S. et. al. (2016) conducted an experimental study on the bond stress between ultra-high performance concrete and 10, 13 and 19 mm steel reinforcements [5]. Cake, K.H. et. al. (2010) conducted an experimental study on the bond stress between ultra-high performance concrete and high strength steel reinforcements. The pull out test based on RILEM standards was used in this study [6]. Finally, these experiments showed that the bond stress of ultra-high performance concrete is 5-10 times higher than conventional concrete. Roy, M. et. al. (2017) used pull out test to determine the bond stress between ultra-high performance concrete and steel reinforcements. In this study, the strength of reinforcements was 415 MPa, and the compressive strength of the concrete was considered between 122.6 MPa to 176.1 MPa. Finally, sliding diagrams of reinforcement in concrete-force were plotted for all specimens [7]. Xing G. et.al. (2015) performed pull out testing to determine the bond stress between ultra-high performance concrete and steel reinforcement [8]. Guizani, L. et. al. (2017) conducted a Local bond stress-slip model for reinforced concrete joints and anchorages with moderate confinement. Guizani, L. et. al. in their paper presents a summary of an experimental investigation and the derivation of a bond-slip model for reinforcing steel embedded in moderately confined concrete under monotonic and cyclic loadings [9]. Yan, C. and Mindes, S. (1994) conducted a Bond between epoxy-coated reinforcing bars and concrete under impact loading [10]. Duchesneau, F., et. al. (2011) conducted a Monolithic and hybrid precast bridge parapets in high and ultra-high performance fibre reinforced concretes [11].

2. Materials and Methods

2.1. Local Bond Measurement

There are several bond tests used to examine the stress transfer from reinforcement to the surrounding concrete. These tests aim to find out how to model the actual interaction between reinforcement and concrete in real structures. However, achieving this goal is difficult because the bond between concrete and reinforcement is complicated by other structural parameters such as flexural bond, lateral pressure, riveting effect and cracking pattern. The suitable bond test should be carefully selected to reflect the actual conditions of the structure. Pull-out test is the oldest, simplest, most inexpensive and less time-consuming method to measure bond stress. In this test, a reinforcement is placed into a cylindrical or cube shaped concrete specimen, and then while concrete is fixed in place, reinforcement is pulled out. Because the reinforcement is subjected to tension and concrete is subjected to compression, the resultant relative strain will lead to relative slip. This test can provide a good comparison between bond strengths and corresponding development lengths. Pull-out test has been used by many researchers to study the effect of various parameters on the bond strength. In this test, short lap splice lengths are used to generate uniform bond stress along reinforcement, which is called local bond.

2.2. Steel Reinforcement Properties

Steel reinforcements having diameters 18 mm were used in determining the Ultra high performance concrete-steel bond strength. Some properties of these steel reinforcements, obtained through tensile test, are given in Table 1.

Table 1. Material properties of steel reinforcement

Diameters (mm)	Elastic modulus (MPa)	Yield strength (MPa)	Ultimate strength (MPa)	Fracture strain (%)
18	201855	531	632	12.11

2.3. Mix Design of UHPC

Several mix designs have so far been offered for ultra-high performance concrete. After studying and testing several mix designs and assessing feasibility of producing them in laboratory, the mix design proposed by Schneider Jianxin was selected to be used in this study. In samples containing nanosilica, micro-silica equivalent to 2.5, 4.5 and 6.5 wt% cement was replaced by nanosilica. The mix designs used in the present study are given in Table 2 in kilograms per cubic meter. Type I cement with a strength class of 525 kg/cm was used in this study. The micro-silica used in this study was purchased from Zhikava company and its chemical composition is presented in Table 3. The superplasticizer was purchased from Silcrete company. This poly carboxylate-based superplasticizer is available with the brand Pema. The nanosilica used in this study were purchased from Lima Nano Pars company that its chemical composition is given in Table 3. The need for thermal treatment is one of the unique properties of ultra-high performance concrete. thermal treatment is a simple process and, in fact, it is an additional phase in the concrete production which in order to strengthen its structure microscopically. Thermal treatment is not required for all applications of ultra-high performance concrete, because without thermal treatment this type of concrete already has a considerable strength and flexibility compared with high performance concrete. According to the reports, thermal treatment improves mechanical properties of concrete by at least 15%. It has also been emphasized that after thermal treatment, durability of concrete is increased and shrinkage and creep are significantly reduced. thermal treatment improves the micro structure of concrete by accelerating the pozzolanic performance of micro-silica and modifying hydration structure. In this study, the specimens were demolded one day after concrete pouring. After demolding, two treatment techniques were applied to the specimens. Some specimens were placed in a vapor environment (90 ° C and 95% moisture) for 48 hours (Figure 1). After this step, the specimens were tested in a standard laboratory environment (22 ° C and moisture variations between 30-50%). The other specimens were placed in the laboratory environment since molding step until testing. Specimen production process was as follows: concrete pouring for all specimens was completed within 20 minutes after mixing. All specimens were placed on a vibrating table during concrete pouring and then were vibrated after pouring for 30 seconds. Then all specimens were covered by a plastic sheet to reduce the rate of loss of moisture.

Figure 1. Thermal treatment

Table 2. Mix design for the ultra-high performance concrete used in tests

Mix design type	Cement	Quartz sand	Quartz powder	Micro-silica	Nanosilica	Water	Superplasticizer
1	665	1020	285	200	0	178	23
2	665	1020	285	183.375	16.625	178	23
3	665	1020	285	170.075	29.925	178	23
4	665	1020	285	156.775	43.225	178	23

Table 3. Chemical composition of microsilica and nanosilica

Element (%)	SiO2	SiC	C	Fe2O2	K2O	P2O5	SO3	Cl	Al2O3	CaO	MgO	Na2O
Micro-silica	93.6	0.5	0.3	0.37	1.01	0.16	0.1	0.04	1.32	0.49	0.97	0.31
Nanosilica	99	0	0	0	0	0	0	0	0	0	0	0

Before the main tests, compressive strength test was performed using standard cylindrical specimens at ages of 7, 28, 90 and 180 days, by breaking three specimens of each design per day. Compressive strength test results obtained for these ages are illustrated in Figure 2 and Table 4.

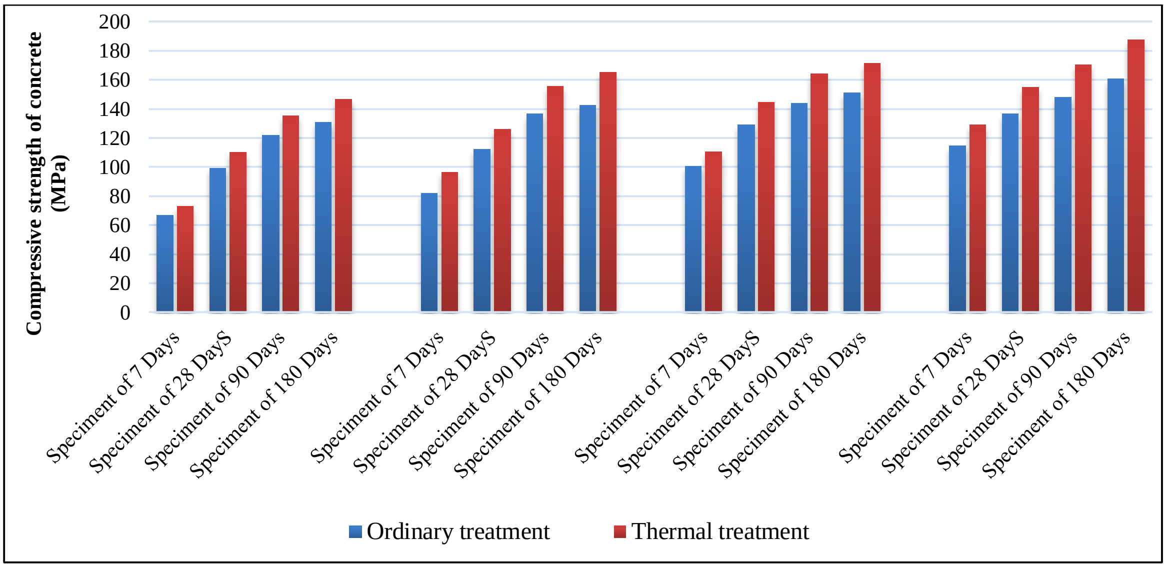

Figure 2. Bar graph of the compressive strength tests for ages of 7, 28, 90 and 180 days

Table 4. The compressive strength test results for ages of 7, 28, 90 and 180 days.

No of Days	Mix design 1		Mix design 2		Mix design 3		Mix design 4	
	Ordinary treatment	Thermal treatment	Ordinary treatment	Thermal treatment	Ordinary treatment	Thermal treatment	Ordinary treatment	Thermal treatment
Specimen of 7 Days	55.7	73.12	68.1	96.45	83.6	110.28	95.3	129.02
Specimen of 28 Days	82.56	110.01	93.61	126.1	107.6	144.33	113.6	155.1
Specimen of 90 Days	101.5	135.01	113.9	155.3	120	164.1	123.1	170.61
Specimen of 180 Days	109	146.61	118.7	165.01	125.9	171.22	134.1	187.74

3. Test Device

The loading method and the test device are shown in Figure 3. Loading was performed as load controlling and the load magnitude was recorded at any moment by an electronic load cell. The LVDT placed at the end of the reinforcement measures the slip of the reinforcement. The records were automatically saved by the data collection system. When the specimen is placed on the support and tensile loading is applied to the reinforcement, a compressive stress is formed at the contact of the specimen and the support. This compressive stress can lead to an increase in bond strength and thus an error in the test results. As a result, in the specimens made based on the RILEM standards, a spacing is considered between the bond zone and the contact point to the support to remove bearing pressure effect. Obviously, there is no contact between the concrete and the reinforcement at this spacing.

Figure 3. Test devices

4. Specimens

In this paper, 24 specimens were tested to assess the effect of nanosilica on local bond between ultra-high performance concrete and steel reinforcements. In this test, we measured the bond stress between ultra-high performance concrete and steel reinforcement of No. 18 with the bond lengths and concrete coatings of d_b,2d_b ,5d_b. Sample naming is so that e.g. in the sample R18C3L2N2.5-1, R18 means that tests were conducted based on RILEM standards and the reinforcement No.18 was tested. C3 represents concrete coating in cube specimens. According to considering three values of d_b,2d_b , and5d_b for concrete coating, C3 represents the third coating which is equal to $3 \times 18 = 54\,mm$ for this specimen. L2 shows the reinforcement-concrete bond length in cube specimens. L2 refers to the second reinforcement-concrete bond length which is equal to $2 \times 18 = 36\,mm$ for this specimen. N2.5 shows the nanosilica percentage in the mix design, and the number 1 or 2 at the end of name indicates type of treatment that can be ordinary or thermal treatment. Table 5 shows specifications of the specimens. In Figure 4, a series of specimens made in the laboratory after demolding are presented.

Table 5. Specimen Specifications

Specimen name	Coating	Length	Specimen name	Coating	Length
R18C1L2N0-1	18	36	R18C1L2N0-2	18	36
R18C1L2N2.5-1	18	36	R18C1L2N2.5-2	18	36
R18C1L2N4.5-1	18	36	R18C1L2N4.5-2	18	36
R18C1L2N6.5-1	18	36	R18C1L2N6.5-2	18	36
R18C2L2N0-1	36	36	R18C2L2N0-2	36	36
R18C2L2N2.5-1	36	36	R18C2L2N2.5-2	36	36
R18C2L2N4.5-1	36	36	R18C2L2N4.5-2	36	36
R18C2L2N6.5-1	36	36	R18C2L2N6.5-2	36	36
R18C3L2N0-1	54	36	R18C3L2N0-2	54	36
R18C3L2N2.5-1	54	36	R18C3L2N2.5-2	54	36
R18C3L2N4.5-1	54	36	R18C3L2N4.5-2	54	36
R18C3L2N6.5-1	54	36	R18C3L2N6.5-2	54	36

Figure 4. Made specimens

5. Result and Discussion

Summary of the results obtained from testing standard RILEM specimens [12] are presented in Tables 6 to 8. Where, u is bond stress and u/$\sqrt{f'_c}$ is normalized bond stress for specimens. Bond length was considered twice the diameter of the reinforcement for all specimens. addition of nanosilica into concrete and thermal treatment increased the compressive strength of concrete. So that in the case of ordinary treatment, the 28-day compressive strength of concrete was increased by about 37 percent by replacing 6.5 percent by weight of cement nanosilica instead of microsilica, while this ratio was more than 40 percent in the case of thermal treatment. With increasing compressive strength of concrete, the bond stress between steel reinforcements and concrete was increased. Also, as can be seen in the tables, Increasing the concrete coating has increased the bond stress and normalized bond stress.

Table 6. bond force and bond stress between concrete and steel reinforcement in the case of ordinary treatment

Specimen name	C	d_b	L	f_c	f_{ct}	Bond force (kg)	Bond stress (Mpa)
R18C1L2N0-1	17.9	18	36	82.56	4.997	3673.54	17.702
R18C1L2N2.5-1	18.2	18	36	93.61	5.321	3990.57	19.230
R18C1L2N4.5-1	18	18	36	107.6	5.705	5217.63	25.143
R18C1L2N6.5-1	18.2	18	36	113.6	5.862	5598.84	26.980
R18C2L2N0-1	30	18	36	82.56	4.997	5835.41	28.120
R18C2L2N2.5-1	36	18	36	93.61	5.321	6993.36	33.700
R18C2L2N4.5-1	36	18	36	107.6	5.705	7413.79	35.726
R18C2L2N6.5-1	37	18	36	113.6	5.862	8097.56	39.021
R18C3L2N0-1	53	18	36	82.56	4.997	8616.36	41.521
R18C3L2N2.5-1	49	18	36	93.61	5.321	8738.58	42.110
R18C3L2N4.5-1	54	18	36	107.6	5.705	9533.38	45.940
R18C3L2N6.5-1	54	18	36	113.6	5.862	9944.68	47.922

Table 7. bond force and bond stress between concrete and steel reinforcement in the case of thermal treatment

Specimen name	C	db	L	fc	fct	Bond force (kg)	Bond stress (Mpa)
R18C1L2N0-2	18	18	36	110.01	5.769	5254.56	25.321
R18C1L2N2.5-2	18.5	18	36	126.10	6.176	5946.22	28.654
R18C1L2N4.5-2	19	18	36	144.33	6.608	6264.76	30.189
R18C1L2N6.5-2	18	18	36	155.10	6.85	6731.47	32.438
R18C2L2N0-2	34	18	36	110.01	5.769	7641.85	36.825
R18C2L2N2.5-2	36	18	36	126.10	6.176	7908.72	38.111
R18C2L2N4.5-2	36	18	36	144.33	6.608	8338.70	40.183
R18C2L2N6.5-2	36	18	36	155.10	6.85	8911.03	42.941
R18C3L2N0-2	54	18	36	110.01	5.769	9722.01	46.849
R18C3L2N2.5-2	53.5	18	36	126.10	6.176	10177.10	49.042
R18C3L2N4.5-2	54	18	36	144.33	6.608	11087.90	53.431
R18C3L2N6.5-2	54	18	36	155.10	6.85	12232.36	58.946

Figures 5 and 6, respectively, reviews the results of the local tension stresses of steel reinforcement and ultra-high performance concrete in conventional mode. Figure 5 shows changes in bond stress of reinforcement No. 18 by increasing reinforcement coating. With increasing reinforcement coating, the bond stress was increased so that in the specimen containing 6.5% nanosilica, with increasing concrete coating by two times and three times increased bond stress 44% and up to 77%, respectively. Moreover, in the specimen containing 4.5% nanosilica, with increasing concrete coating by two times and three times increased bond stress 42% and up to 82%, respectively. Figure 6 shows changes in bond stress of reinforcement No. 18 by reducing nanosilica content in concrete under ordinary treatment, so that with increasing nanosilica content from zero to 6.5% by weight of cement, the bond stress in R18C1L2-1, R18C2L2-1 and R18C3L2-1 specimens was increased by 54%, 38% and 15%, respectively. Figure 6 shows the variation in the bond stress of reinforcement No. 18 by decreasing the amount of nanosilica in concrete in conventional curing mode. The bond stress in the R18C1L2-1 sample has increased by increasing the amount of nanosilica from zero to 2.5%, 4.5% and 6.5% of cement weight as much as 6.8%, 42% and 52%, respectively. The bond stress in the R18C2L2-1 sample has increased by increasing the amount of nanosilica from zero to 2.5%, 4.5% and 6.5% of cement weight as much as 19.8%, 27% and 38% respectively. The bond stress in the R18C3L2-1 sample has increased by increasing the amount of nanosilica from zero to 2.5%, 4.5% and 6.5% of cement weight as much as 1.4%, 10.6% and 15.4%, respectively.

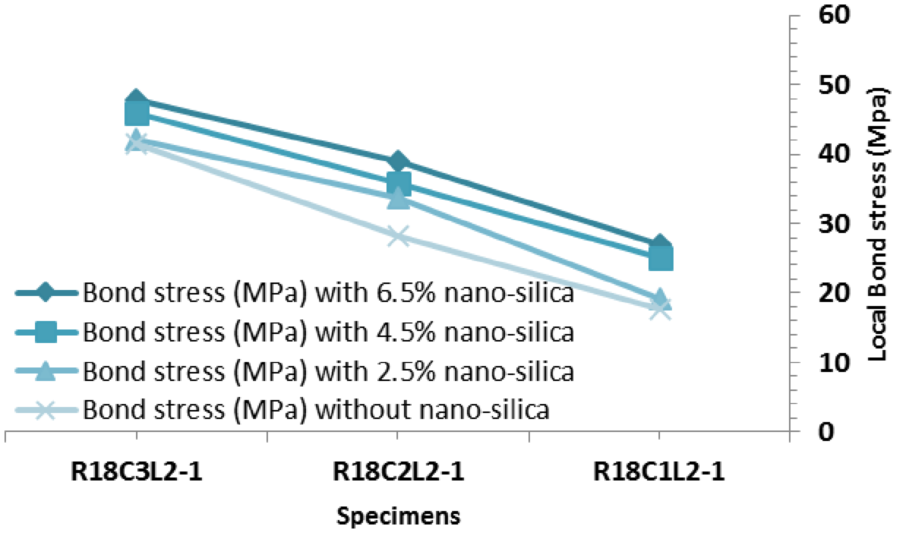

Figure 5. bond stress of reinforcement No. 18 by increasing reinforcement coating

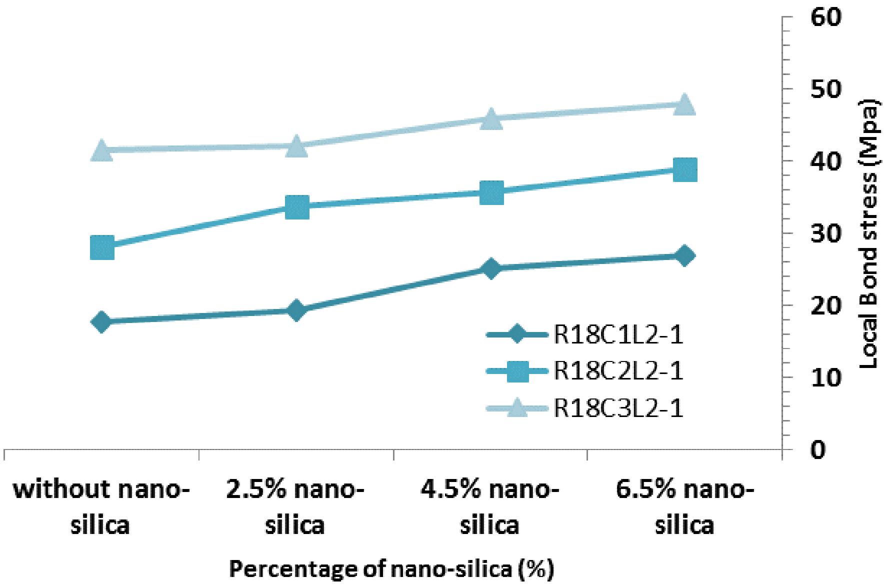

Figure 6. bond stress of reinforcement No. 18 by reducing nanosilica content in concrete

Similarly, Figures 7 and 8 illustrate changes in bond stress of reinforcement No. 18 by increasing reinforcement coating and reducing nanosilica content in concrete in the case of thermal treatment. The results indicate that with increasing reinforcement coating and increasing nanosilica content, the bond stress between steel reinforcements and concrete was increased. Figure 7 shows changes in bond stress of reinforcement No. 18 by increasing reinforcement coating. With increasing reinforcement coating, the bond stress was increased so that in the specimen containing 6.5% nanosilica, with increasing concrete coating by two times and three times increased bond stress 32% and up to 81%, respectively. Moreover, in the specimen containing 4.5% nanosilica, with increasing concrete coating by two times and three times increased bond stress 33% and up to 77%, respectively. Figure 8 shows the variation in the bond stress of reinforcement No. 18 by decreasing the amount of nanosilica in concrete in conventional curing mode. The bond stress in the R18C1L2-2 sample has increased by increasing the amount of nanosilica from zero to 2.5%, 4.5% and 6.5% of cement weight as much as 13%, 19%, and 28%, respectively. The bond stress in the R18C2L2-2 sample has increased by increasing the amount of nanosilica from zero to 2.5%, 4.5% and 6.5% of cement weight as much as 3%, 9%, and 16%, respectively. The bond stress in the R18C3L2-2 sample has increased by increasing the amount of nanosilica from zero to 2.5%, 4.5% and 6.5% of cement weight as much as 4.6%, 14%, and 25%, respectively.

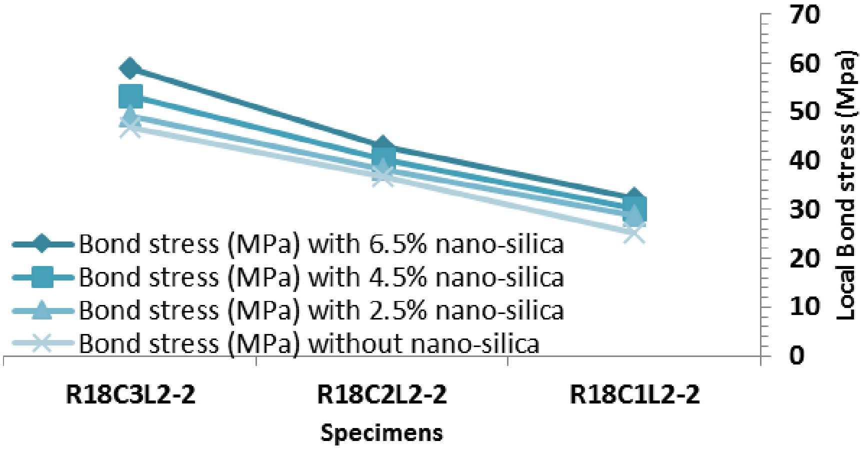

Figure 7. bond stress of reinforcement No. 18 by increasing reinforcement coating

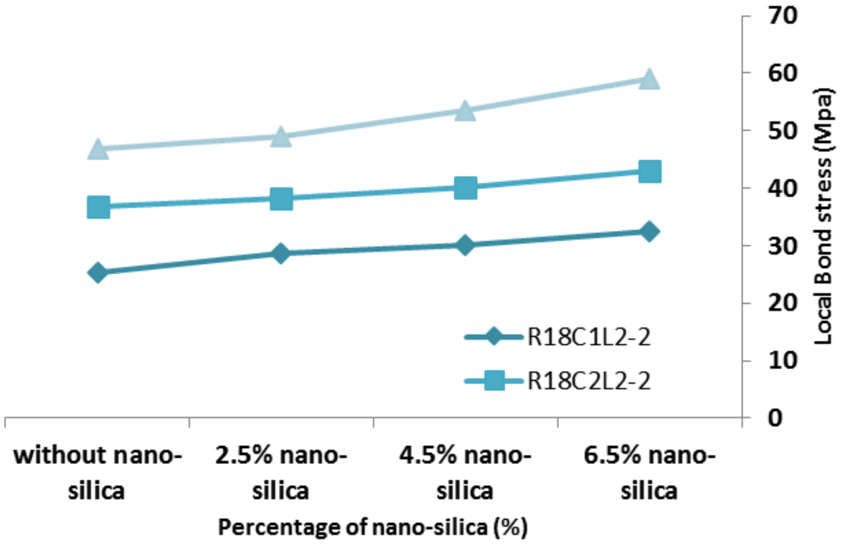

Figure 8. bond stress of reinforcement No. 18 by reducing nanosilica content in concrete

Table 8 shows the bond stress and normalized bond stress between steel reinforcement and concrete in the case of ordinary and thermal treatments. As can be seen, with increasing reinforcement coating and increasing the percentage of nanosilica, the bond stress was increased.

Table 8. The bond stress and normalized bond stress between steel reinforcement and concrete (ordinary and thermal treatments)

Specimen name	Bond stress u	Normalized bond stress $u/\sqrt{f'_c}$	Specimen name	Bond stress u	Normalized bond stress $u/\sqrt{f'_c}$
R18C1L2N0-1	17.702	1.948	R18C1L2N0-2	25.321	2.414
R18C1L2N2.5-1	19.230	1.988	R18C1L2N2.5-2	28.654	2.552
R18C1L2N4.5-1	25.143	2.424	R18C1L2N4.5-2	30.189	2.513
R18C1L2N6.5-1	26.980	2.531	R18C1L2N6.5-2	32.438	2.605
R18C2L2N0-1	28.120	3.095	R18C2L2N0-2	36.825	3.511
R18C2L2N2.5-1	33.700	3.483	R18C2L2N2.5-2	38.111	3.394
R18C2L2N4.5-1	35.726	3.444	R18C2L2N4.5-2	40.183	3.345
R18C2L2N6.5-1	39.021	3.661	R18C2L2N6.5-2	42.941	3.448
R18C3L2N0-1	41.521	4.570	R18C3L2N0-2	46.849	4.467
R18C3L2N2.5-1	42.110	4.352	R18C3L2N2.5-2	49.042	4.367
R18C3L2N4.5-1	45.940	4.429	R18C3L2N4.5-2	53.431	4.447
R18C3L2N6.5-1	47.922	4.496	R18C3L2N6.5-2	58.946	4.733

According to the test observations, failure of the specimens can be divided into three main modes of pull-out, split, and bar yielding. In the mode of pulling the reinforcement out of the concrete by removing the concrete keys between reinforcement treads as much as concrete shear capacity, the keys are slipped off and the reinforcement is pulled out of concrete. In this case, the concrete specimen remains intact without any cracks or damage indicating destruction. This failure mode was observed in highly coated specimens. In the split mode, due to the reaching of hoop tensile stresses to the ultimate tensile strength of concrete, failure is done with wide radial cracking and splitting the specimen into two or more parts (Figure 9). The reinforcement bar yielding mode occurs due to the long bond length or high strength of concrete. In this case, before the bond zone reaches the ultimate capacity, the reinforcement yields.

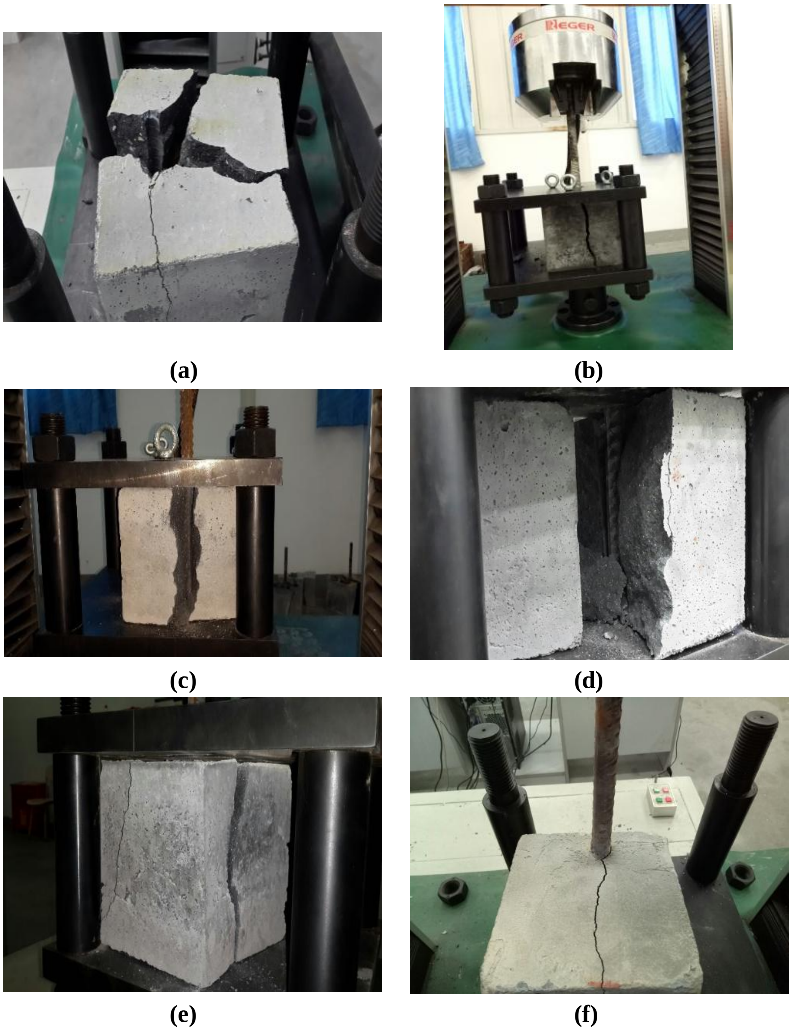

Figure 9. Split in the specimen: (a) R18C3L2N6.5-1; (b) R18C3L2N2.5-1; (c) R18C2L2N6.5-1; (d) R18C2L2N2.5-1; (e) R18C1L2N6.5-1; (f) R18C1L2N0-1

6. Modification of the Local Bond Stress Equation

In this section, the local bond stress equation proposed by Esfahani & Rangan [13] for ultra-high performance concrete is analyzed. This equation was proposed in 1998 and it was generalized and modified Tepfers theory as follows:

$$u_c = 8.6\frac{\left(\frac{c}{d_b}+0.5\right)}{\left(\frac{c}{d_b}+5.5\right)} fct : f_c' \succ 50Mpa \tag{1}$$

Where, u_c is the bond stress in MPa, c is the minimum concrete coating on the reinforcement, d_b is the diameter of the reinforcement, $f_{ct} = 0.55\sqrt{f_c'}$, and f_c' is the compressive strength of the concrete. The initial value of f_b is used to correct (modify) the equation 1.

$$f_b = \frac{\frac{c}{d_b}+0.5}{1.75} f_{ct} \tag{2}$$

Where, c is the minimum concrete coating on the reinforcement, d_b is the diameter of the reinforcement , $f_{ct} = 0.55\sqrt{f_c'}$, and f_c' is the compressive strength of the concrete. By placing the equation 2 in the general form of Equation 1, we have:

$$u_c = 1.75(c_1 \times \frac{f_b}{\left(\frac{c}{d_b} + c_2\right)}) \tag{3}$$

Where, c_1 and c_2 are constant coefficients. Equation 3 can be simplified to the following linear equation:

$$\frac{c}{d_b} = 1.75 \times c_1 \times \left(\frac{f_b}{u_c}\right) - c_2 \tag{4}$$

$\frac{f_b}{u_{test}}$ and $\frac{c}{d_b}$ values were calculated for specimens and after averaging in each category, they are plotted in Figures 10 and 11 for ordinary and thermal treatments, respectively. the line fitted to the data is as follows:

For concrete with ordinary treatment:

$$\frac{f_b}{u_c} = 3.1806\frac{c}{d_b} + 1.4699 \tag{5}$$

For concrete with thermal treatment:

$$\frac{f_b}{u_c} = 3.6422\frac{c}{d_b} + 1.7916 \tag{6}$$

Using Equations 5 and 6, Equation 1 is modified for ultra-high performance concrete as follows:

$$u_c = 42.96455\frac{\frac{c}{d_b} + 0.5}{\frac{c}{d_b} + 15.075} f_{ct} : f_c' \leq 110 Mpa \tag{7}$$

$$u_c = 20.77922\frac{\frac{c}{d_b} + 0.5}{\frac{c}{d_b} + 3.436} f_{ct} : f_c' \succ 110 Mpa \tag{8}$$

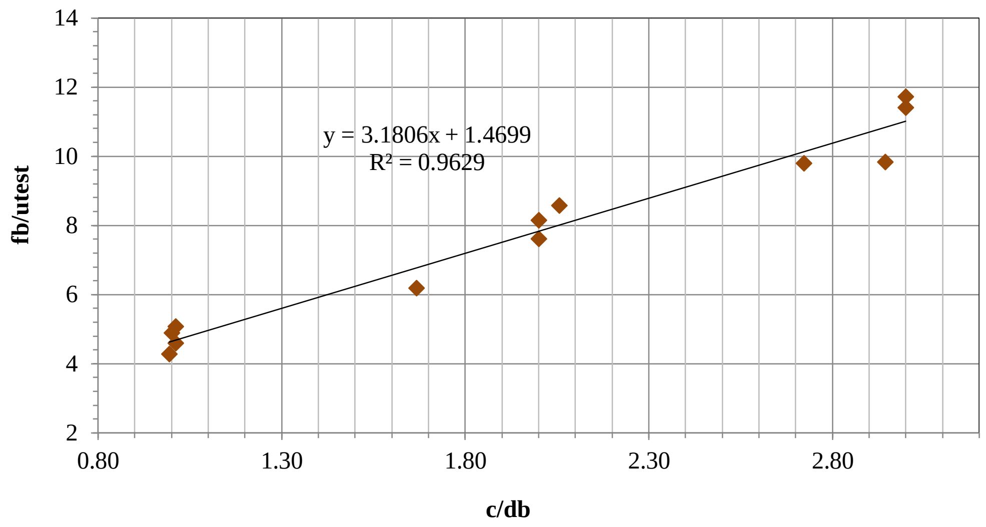

Figure 10. $\frac{f_b}{u_{test}}$**vs** $\frac{c}{d_b}$ **plot obtained from tests for the ordinary treated specimens**

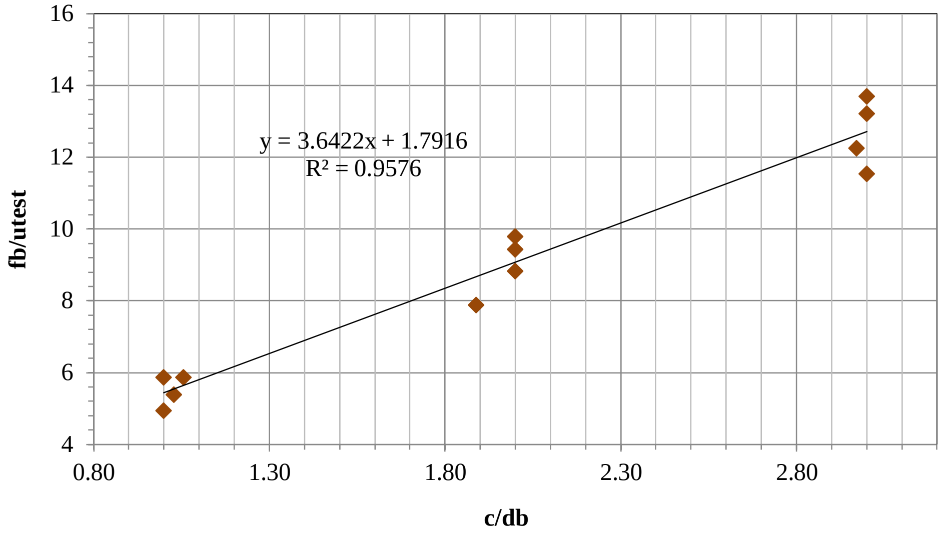

Figure 11. $\frac{f_b}{u_{test}}$ **vs** $\frac{c}{d_b}$ **plot obtained from tests for the thermal treated specimens**

7. Conclusions

In this research, we investigated the local bonding stress of the ultra-high performance concrete and steel reinforcement. The results of the research show that the relationship of bond stress is reformed as follows.

$$u_c = 20.77922 \frac{\frac{c}{d_b} + 0.5}{\frac{c}{d_b} + 3.436} f_{ct} : f_c' \succ 110 Mpa \tag{9}$$

Also Addition of nanosilica into concrete and thermal treatment increased the compressive strength of concrete. So that the 28-day compressive strength of concrete was increased about 37% by replacing 6.5 percent weight of cement microsilica with nanosilica. While this ratio was more than 40 percent in the case of thermal treatment. With increasing reinforcement coating, the bond stress was increased. so that in the specimen containing 6.5% nanosilica, with increasing concrete coating by two times and three times increased bond stress 44% and up to 77%, respectively.

When concrete in the case of normal treatment, with increasing reinforcement coating, the bond stress was increased so that in the specimen containing 6.5% nanosilica, with increasing concrete coating by two times and three times increased bond stress 44% and up to 77%, respectively. Moreover, in the specimen containing 4.5% nanosilica, with increasing concrete coating by two times and three times increased bond stress 42% and up to 82%, respectively.

In addition, the bond stress in R18C1L2-1 sample has increased by increasing the amount of nanosilica from zero to 2.5%, 4.5% and 6.5% of cement weight as much as 6.8%, 42%, and 52%, respectively. The bond stress in R18C2L2-1 sample has increased by increasing the amount of nanosilica from zero to 2.5%, 4.5% and 6.5% of cement weight as much as 19.8%, 27%, and 38%, respectively. The bond stress in R18C3L2-1 sample has increased by increasing the amount of nanosilica from zero to 2.5%, 4.5% and 6.5% of cement weight as much as 1.4%, 10.6%, and 15.4%, respectively. When concrete in the case of thermal treatment, with increasing reinforcement coating, the bond stress was increased so that in the specimen containing 6.5% nanosilica, with increasing concrete coating by two times and three times increased bond stress 32% and up to 81%, respectively. Moreover, in the specimen containing 4.5% nanosilica, with increasing concrete coating by two times and three times increased bond stress 33% and up to 77%, respectively. The bond stress in R18C1L2-2 sample has increased by increasing the amount of nanosilica from zero to 2.5%, 4.5% and 6.5% of cement weight as much as 13%, 19%, and 28%, respectively. The bond stress in R18C2L2-2 sample has increased by increasing the amount of nanosilica from zero to 2.5%, 4.5% and 6.5% of cement weight as much as 3%, 9%, and 16%, respectively. The bond stress in R18C3L2-2 sample has increased by increasing the amount of nanosilica from zero to 2.5%, 4.5% and 6.5% of cement weight as much as 4.6%, 14%, and 25%, respectively.

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