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Effect of Casting Temperature on Bond Stress of Reinforced Concrete Structure

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I. Introduction

Reinforced concrete is a common practice in Civil Engineering. It acts as a composite member when reinforcing bars and concrete residing together. Then they offer most stiffness and durability than others. It is almost depends on their bond behavior. Concrete is placed under many different atmospheric conditions. Sometimes it is placed at hot environment or cold environment. So, temperature has a great impact on reinforced concrete structure.

Concrete this is placed at low temperature develops higher ultimate strength, greater durability and is less subject to thermal cracking [1]. And concrete this is placed at hot temperature, leads to rapid hydration and this results in an increased rate of slump which leads to expedited setting and to a lower long term strength of concrete [2]. The effect of temperature on water demand is mainly brought about by its effect on the rate of cement hydration [3]. When water comes to the cement particle, hydration reaction starts. This hydration reaction is a heat generating reaction. When the ambient temperature is increased with atmosphere then the rate of chemical reaction is increased naturally. So, the ultimate degree of hydration increases with temperature [4]. As a result of the accelerated hydration, initial and final setting times are both reduced with the rise in temperature. A14°C rise in temperature from 10 to 24°C reduced the initial setting time by 8 h while the same rise in temperature from 24 to 38°C reduced the latter by 5 h only [5]. And hot weather conditions more water is required for a given mix to have the same slump, i.e. the same consistency. A 25mm decrease in slump is brought about by a 10°C increase in concrete temperature [6]. The rate of reaction increases with temperature but so does the rate of evaporation from an exposed surface. The ultimate strength of concrete cured at low temperature is generally greater than that of concrete cured at a high temperature, but extremes of temperature generally have a negative effect [7].Concrete cast and cured at high temperature exhibits the expected increased early-age strength, it later-age strength is adversely affected [8,9,10].A better understanding of effect of mixing and curing temperature on reinforced concrete would no doubt aid in the development of concrete structure under various environmental condition especially temperature to predict the bond strength of reinforced concrete structures. The objectives of this study are to investigate the bond strength of reinforced concrete under varying mixing and curing temperature.

II. Experimental Program

The experimental work was carried out to the effect of mixing and curing temperature on bond stress of reinforced concrete. The variable parameters studied and materials and methods involved were as follows:

a) Materials

The experimental program consists of main four types of materials. These are mainly Cement Type I (Ordinary Portland Cement), crushed burned brick, sea bed sand and reinforcing bar.

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Table 1 : Chemical composition of ordinary Portland cement materials (Mass %)

Oxide Composition	Ordinary Portland Cement
CaO	62.75
SiO_2	20.83
Al_2O_3	5.29
Fe_2O_3	3.50
MgO	0.52
SO_3	2.44
Na_2O	0.23
Total	95.56
Ignition loss	2.65

i. *Cement*

Cement Type-I, Ordinary Portland Cement was used as a binding materials. The oxide compositions of ordinary Portland cement are summarized in Table (1).

Aggregate:

The properties of fine and coarse aggregates that were used are summarized in Table (2). Sea bed sand was used as a fine aggregate and crushed burned brick was used as a coarse aggregate. The maximum size of coarse aggregate was 19 mm.

Table 2 : Physical properties of coarse and fine Aggregate

Properties	Coarse aggregate (Crushed Burned Brick)	Fine aggregate (Sea Bed Sand)
Maximum aggregate size, (mm)	19.0	2.38
Unit weight(Kg/m^3)	861.02	1555.58
Specific gravity	2.04	2.64
Fineness modulus	-	2.72
Absorption, (%)	18.25	3.19

b) *Test Specimens*

Six groups of pullout specimens consisting of 100mm (4 in.) x 200mm (8in.) concrete cylinders rebar embedded axisymmetrically were tested. Deform rebar used in three groups and plain rebar used in another three group. Every group contained four specimens. Rebar was casted vertically from the top of the cylinder. Fig.1 shows the pullout test specimen dimension. Type of specimens and rebar, rebar diameter, embedded length, compressive strength and splitting tensile strength are provided in Table (3). For compressive strength test, same size of concrete cylinder was tested for 3 days, 7 days, 28 days and 90 days sample.

c) *Concrete Mix Design*

The concrete mix for every specimen was based on the mix design. The weight proportion of the concrete of the mixture was 1 (cement) : 1.4 (coarse aggregate) : 2.5 (fine aggregate): 0.5 (water), giving a water to cement ratio (W/C) of 0.5. The concrete was mixed by following the hand mixing method. The concrete mix consisted of 147kg/m^3 water, 295 kg/m^3 cement, 445 kg/m^3 sea bed sand, 500 kg/m^3 burned crushed brick.

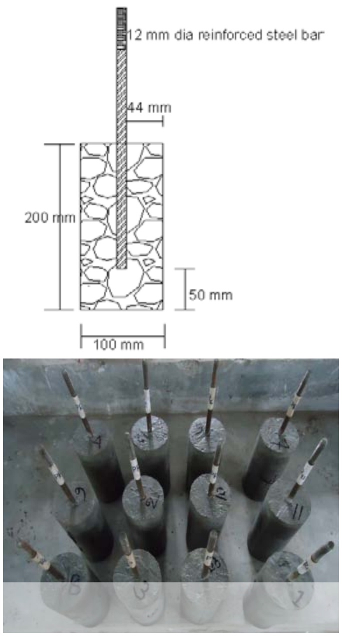

Figure 1 : Dimension of pullout specimen, schematic diagram (left), pictorial diagram(right)

d) *Test Method and Loading Instrumentation*

Mixing and curing temperature are the main parameter in this research work. Three type of temperature (15°C, 30 °C, and 45 °C) were observed in this study. During sample preparation and curing these temperatures were successively controlled into the laboratory. According to the ASTM C39, 100 mm dia. and height of 200 mm cylindrical concrete specimen were tested by compression strength testing machine for different age of concrete for different mixing and curing temperature. According to the ASTM C496-90, splitting tensile strength test of cylindrical concrete was observed for 28 days for each mixing and curing temperature. And finally bond stress of reinforced concrete was tested according to the illustrated fig. (2).

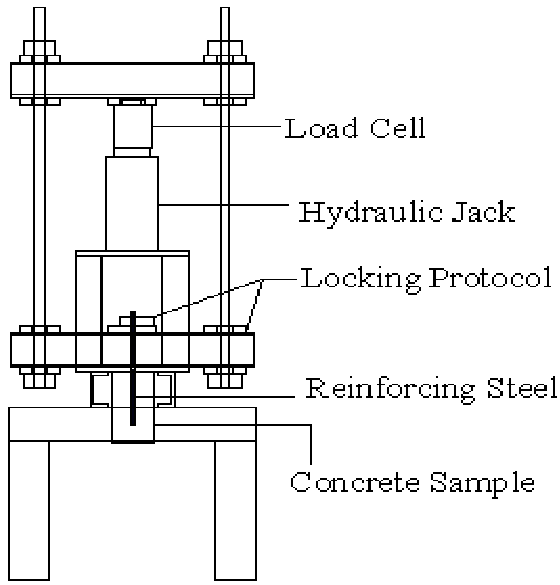

Figure 2 : Test aggangement: compressive strength (left) and pullout test setup frame (right)

III. Results and Discussion

In compressive strength test, measurements of compressive load were taken from compressive strength testing machine. Compressive strength was calculated as compressive loads were divided by cross sectional area of concrete cylinder. Measurements of compressive strength were observed for three mixing and curing temperature such as 15°C, 30°C, 45°C and for several four days (3, 7,28 and 90 days).

The results of compressive strength are plotted in fig. 3 for different temperature for several days. The fig.3 is illustrated that mixing and curing temperature has the direct effect on compressive strength. It shows that at beginning stage of strength gaining process, 45^{0}C casting temperature sample has the higher value of strength than 15^{0}C mixing temperature sample. But 28 days and 90 days strength shows that reverse of 7 days strength value. Due to the high temperature, rate of hydration of cement has increased and initial setting time has decreased.

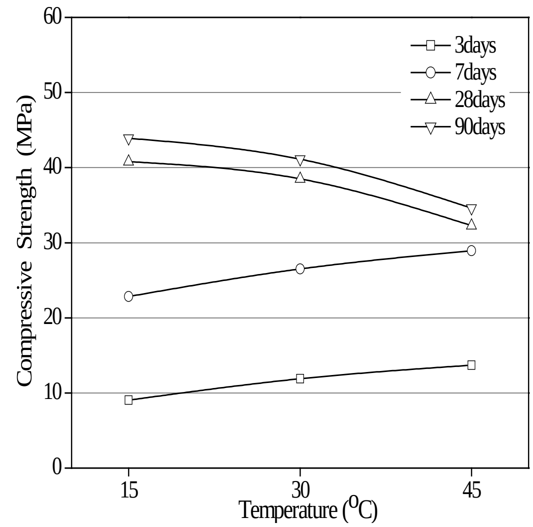

Figure 3 : Effect of mixing and curing temperature on compressive strength of concrete cylinder

Due the low temperature, heat of hydration has been absorbed by the ambient temperature of aggregate. For this hydration rate has decreased and initial setting time has increased. It can conclude considering the initial setting time, for lower setting time 45^{0}C sample gives higher early age strength but long time strength of this sample gives low value and 15^{0}C sample has the reverse strength due to the higher setting value.

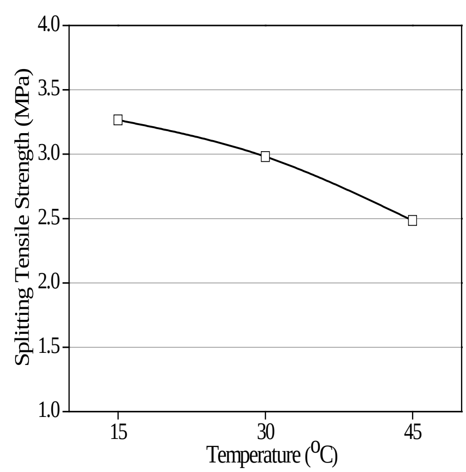

Figure 4 : Effect of mixing and curing temperature on splitting tensile strengthof concrete cylinder

In splitting tesile strength test, the measurements of tensile load were taken from cpmpressive strength testing machine. Splitting tensile strength was calculated as two times of tensile load were divided by surface perimeter of concrete cylinder. Measurements of splitting tensile strength were obseved for different mixing and curing temperature for 28 days. Fig.4 is illustrated that the effect of mixing and curing temperature on splitting tensile strength. It has a small effect on splitting tensile strength. It gives the downward slope of strength from 15^{0}C to 45^{0}C mixing and curing temperature. Lower temperature gives 24% more tensile strength than higher mixing and curing temperature.

Table 4 : Summary of pullout test results of specimens

Specimen	Maximum Load (kN)	Maximum Nominal Steel Stress (MPa)	Failure Slip (mm)	Maximum Bond Stress (MPa)
D15DC	49.35	436.35	0.75	8.59
D30DC	42.98	380.03	1.10	7.48
D45DC	35.78	316.36	0.85	6.23
P15DC	34.01	300.71	0.88	5.92
P30DC	27.46	242.78	0.77	4.78
P45DC	21.37	188.95	0.35	3.72

In Pullout test, measurement of bond load and corresponding slip were taken from the pullout test setup arrangement. Bond stress was calculated as the maximum bond load was divided by the embedded steel surface perimeter. It was observed for deform and plain reinforcing bar as well as different mixing and curing temperature. Table (4) shows that bond stress slip relationship between deform and plain reinforcing bar for different mixing and curing temperature. The pick point of bond stress-slip relationship is indentified as a maximum bond load and corresponding bond slip. The average calculated maximum nominal bond stress, bond load, failure slip and calculated maximum bond stress are shown in Table (4).

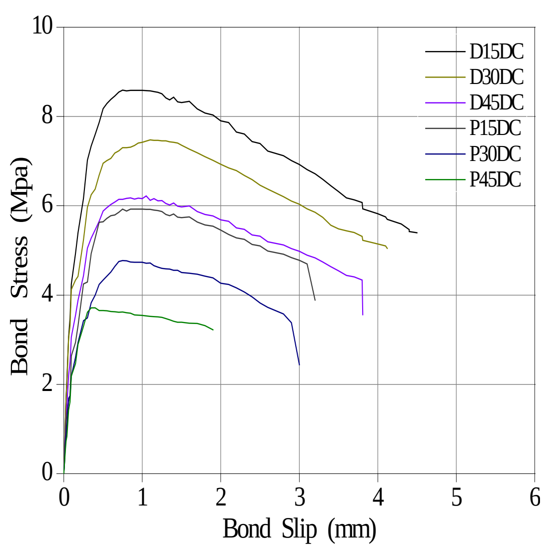

Figure 5 : Effect of mixing and curing temperature on bond stress-slip relationship

The fig. 5 shows that bond stress of deform rebars are always greater than plain bars. Deform rebars show initially more incresing bond nature with respect to slip value than plain rebars. But after maximum bond load these give more slip value than plain rebars.Due to adition and friction defrom rebars give better bond stress than plain rebar. Friction can contribute up to 35%of the ultimate strength governed by the splitting of the concrete cover [11]. For deformed bars, bond stress depends on the mechanical interlocking betwwen ribs and concrete keys. The ultimate bonstrength is reached , shear crack begin to form the concrete between the robs as interlocking forces induce large bearing stress around ribs and large slip occure[12]. It is clear in fig.5 that mixing and curing temperature have a great impact on bond stress. D15DC gives more bond stress and slip value than D30DC and D45DC and P15DC sample gives better bond strength thanP30Dc and P45DC.

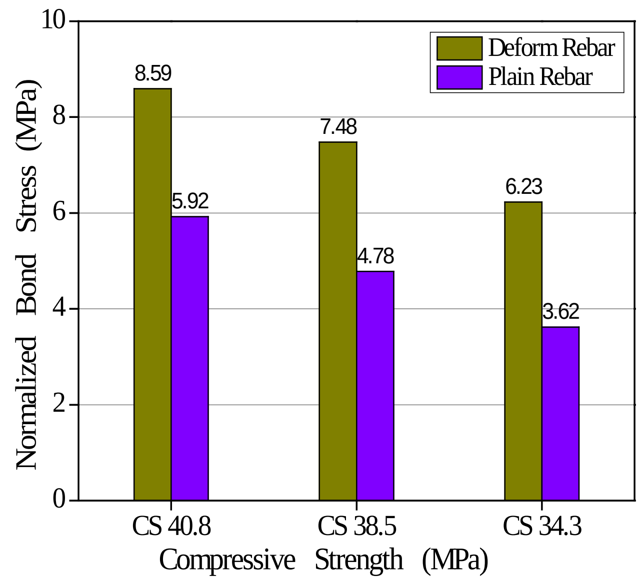

Figure 6 : Variation of normalized bond stress under deform and plain rebars

According to the fig.3, low temperature has great impact on long term strength of reinforced concretea and it illustrates that 15°C mixing and curing temperature sample shows 21% more compressive for 28 days than 45°C sample. Compressive strength is considered to be a significant parameter in bond behavior because the force between steel and concrete is transferred mainly by bearing and bond[13]. It has been found that the bond of high strength concrete is proportional to the compressive strength of concrete[14]. The fig.6 explains the variation of normalized bond stress for deformed and pain reinforcing bars. It shows that D15DC sample gives 27.4% more bond stress than D45DC sample and P15DC sample shows 38.5% more bond stress than P45DC sample. Again average of D15DC, D30DC and D45DC samples gives nearly 36% more bond stress than P15DC,P30Dc and P45DC samples.

IV. Conclusion

Based on the results of this research work, the following conclusions can be drawn with respect to different mixing and curing temperature of concrete.

Lower mixing and curing temperature leads to increase initial setting time of concrete that increase 21% compressive strength for 28 days than higher mixing and curing temperature samples. It increases 27% - 38.5% more bond stress than higher mixing and curing temperature sample. Deform reinforcing bars give 36% more bond stress than plain reinforcing bars due the adhesion, friction and mechanical interlocking of deform rebar's. Finally, lower mixing and curing temperature presents better results than higher mixing and curing temperature.

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