Effect of Cement Content on Compressive and Bonding Strength with Steel Bar Reinforcement

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Abstract. Concrete is the most important building material due to the availability of its constituent materials and its easy manufacturing; it is commonly reinforced with a steel bar to resist the tensile stresses. The present research discusses the effect of cement content on the bonding strength with the steel bar reinforcement as well as the concrete strength while fixing the fine/coarse aggregate proportion, the slump and the water/cement ratio. Two series have been produced by using different types of steel bars (smooth and deformed) with a different cement content of (250, 300, 350, 400 and 450 kg/ m³). These two parameters were used to study the effect of the cement content and the mechanical interlocking on the bonding strength between concrete and steel bars. The results of this study showed that the compressive strength increases with the increasing of cement content up to 400 kg / m³, and then there is no significant improvement in compressive strength. However, the bonding strength with the steel bar increases even at 450 kg / m³. For any cement content, the deformed bars exhibited a better bonding strength of several times than the smooth bars.

Keywords: Cement Content; Compressive Strength; Interfacial Bonding Strength; Pull-out Test

1. Introduction

Steel reinforcement is an essential element in concrete construction because of its ability to compensate for the weakness in the tensile strength of plain concrete and maintains the ductility performance of the members. Three main factors in reinforced concrete are working together to acquire optimum performance: Concrete strength, Steel strength and the interfacial bonding strength [1]. Coupled with many sub factors which have a particular effect on the bonding strength with steel bar reinforcement including: cement content and external texture of steel bar (the subject of this study), type of cement [2], water/cement ratio [3], type and size of aggregate [4,5], curing methods [6], age of concrete, temperature [7,8], sulfate attack [9,10], bar diameter [11,12], effective length [13], type of admixture [14] and steel corrosion [15,16].

Chowdhury [17] investigated the effect of concrete age on the bonding strength with steel bar and found that the bonding strength increased with age due to the progress of the hydration process which occurs
between the un-hydrated cement and the water, that is responsible to increase concrete strength during the curing phase.

Corral at el. [9] studied the effect of sulfate on reinforced concrete, it was found that the presence of these sulfates lead to the deterioration of concrete through the interaction between the alkali hydroxides in cement paste and the silicate constituents in the aggregates. In addition, these sulfates also lead to an increase in the corrosion of steel reinforcement. In fact, there are no chemical bond between steel bar and cement components, however corrosion represents a weak cover which can deteriorate the proper adhesion [15]. Consequently, these two factors lead to a weakness in the interfacial bonding strength. In that case, it was recommended to use fly ash (FA) and silica fumes to increase the resistance of concrete against sulfate attack.

Lubloy and György [7] studied the effect of temperature on reinforced concrete and found that the high temperatures lead to a change in the chemical composition due to changes in water content and physical changes due to the differences in the coefficient of thermal expansion (CTE) of the components [18]. There was a significant decrease in the bonding strength between 400 °C and 500 °C. This degradation in the bonding strength can be explained by the decomposition of portlandite at 450 °C. Steel bar diameter and concrete strength have also an effect on the bonding strength. It was found that the transmission of the axial force from the reinforcing steel bars to the surrounding concrete leads to deformations in the concrete components due to the tangential stress component along the contact surface with the reinforcing steel bars. Increasing the diameter of the reinforcing steel bars will lead to weakness in the bonding strength compared with the lowest diameter for the same ratio of reinforcement [12]. Analysis and design software can help to predict a virtual behavior of the reinforced concrete and the mode of failure for any complex structure [19].

Because of the lack of scientific research dealing with the impact of cement content on the bonding strength with a steel bar and the importance of this characteristic to feed special analysis computer programs (finite element) by experimental data. This study will draw diagrams showing the effect of cement content, steel texture and concrete strength on the interfacial bonding strength with steel reinforcement.

2. Experimental works

Two series have been made by using different types of steel bars (smooth and deformed), they were used to study the effect of cement content and mechanical interlocking on the interfacial bonding strength. Therefore, 30 specimens for pull out tests were produced from five different mixtures (differ only in the percentage of cement content 250, 300, 350, 400, 450 kg/m³). Several trials of a slump test were done to obtain constant workability for all different mixtures while fixing other parameters (the water / cement ratio and the fine/coarse aggregates proportion), it was found that a very necessary of using a different dosage of admixture to obtain the same workability for the mixtures, the results were recorded in Table 1. The proportions of the constituent materials for concrete mixture were calculated when assumed that the ratio of coarse aggregate (y) represents twice of fine aggregate (x) (y = 2x). The percentage of total voids were assumed to be 2%. Thus, the volumetric equation of the proportional components was used to find out the weight of cement, fine aggregate, and coarse aggregate.

\[
\frac{c}{3.6} + \frac{x}{2.6}c + \frac{y}{2.7}c + 0.3c = 0.98
\]

\[
y = 2x
\]

Where: c represents cement weight; y and x represent gravel and sand weight, respectively.

The steel bars were very well cleaned from the out-surface corrosion to give a proper adhesion between steel reinforcement and concrete, Figure 1.
Table 1. State mix proportion and slump test for each mixture.

| Group No. | Cement content (kg/m³) | Mix proportion (Cement : Sand : Gravel) | Water/Cement ratio | Admixture/Cement ratio | Slump (mm) |
|-----------|------------------------|---------------------------------------|--------------------|------------------------|------------|
| 1         | 250                    | 1 : 2.932 : 5.86                      | 0.3                | 1%                     | 5          |
| 2         | 300                    | 1 : 2.35 : 4.7                        | 0.3                | 0.9%                   | 8          |
| 3         | 350                    | 1 : 1.939 : 3.878                     | 0.3                | 0.8%                   | 10         |
| 4         | 400                    | 1 : 1.6284 : 3.2568                   | 0.3                | 0.7%                   | 13         |
| 5         | 450                    | 1 : 1.3865 : 2.773                    | 0.3                | 0.6%                   | 15         |

Figure 1. Show the steel bars before and after corrosion cleaning.

The tested specimens were made by using cylindrical steel molds with diameters of 100 mm and height of 200 mm, to ensure that the steel bar is fixed at the middle of the cylindrical mold, circular wooden parts in the bottom were used. The effective length of steel bar was determined according to the ACI code (6 bar diameter), it was chosen to be 70 mm, since using steel bar of 12 mm diameter, this process was achieved when plastic tubes are inserted from the top and bottom sides as in the Figure 2.

Some laboratory tests have been carried out for the materials used in this research to ascertain their quality and suitability for use as follows: The sifting process is done by using the standard sieves according to the ASTM tests for the fine and coarse aggregate of maximum size of 12 mm. The remaining weight is calculated on each sieve and recorded, then the percentages were calculated to draw the grading of aggregate with the upper and lower standard limits of each sample, Figure 3.
3. Results and discussion

Physical tests such as workability by slump test are very important to give an idea on concrete flowability. In scientific terms, it must be controlled to make a comparison between different mixtures. Then, mechanical tests, such as compressive strength and pull out tests were done to observe the effect of steel bar texture and cement content on the interfacial bonding strength.

3.1 Slump test

The slump test for each concrete mixture was tested to determine its workability. The test process was carried out when filled the steel cone with a concrete sample with three compacted layers. The cone was lifted and the amount of slump of concrete was measured as shown in Figure 4 and the results were recorded. Superplasticizer was added to control obtaining constant workability for the five mixtures. In spite of using constant w/c ratio and the reduction in the admixture (HP580) content, the workability increased when increased the cement content. This result may be explained by the fact that the fine
material (cement paste) is increased, this can improve the lubrication between aggregate particles, thus the slump value increased.

![Figure 4. Show the slump test.](image)

3.2 Compressive test

The universal compression machine was used to obtain compressive strength after 28 days for 30 cubic specimens to study the effect of increasing cement content on the compressive strength when the fine/coarse aggregates proportion, the W/C ratio, and the workability were constant for the five mixtures, Figure 5.

The compressive strength increased when increasing cement content up to 400 kg/m$^3$, which is the expected behavior. Whereas, it was observed that the compressive strength of the mixture containing 450 kg/m$^3$ had the same value or small decrease when compared with the previous one. This is due to the relative increase of cement paste versus aggregate content in the mix, which is often responsible for mechanical resistance.

![Figure 5. shows the effect of cement content on concrete compressive strength](image)

3.3 Pull out test

After 28 days of water curing, results of the pull-out test for 30 specimens of cylindrical concrete reinforced either with smooth or deformed bar were recorded. The tensile machine was used to draw the relationship between the tensile force and the deformation (slip). Therefore, a steel setup suggested
by [17] was used, in which the concrete cylinder was installed and then held by the machine. As a result, the cement content and the steel bar surface texture were investigated to study their effects on the interfacial bonding strength, Figure 6.

![Figure 6](image1.png)

**Figure 6.** Pull-out test (A) for smooth bar and (B) for deformed bar.

For all mixtures containing different cement content, Specimens reinforced with deformed bar exhibit higher resistance to pull out force than specimens reinforced with smooth bar. These experiments confirmed that the mechanical interlocking between the cement paste and the inner groove of the deformed bar, creating an additional resistance force to the bonding force extending along the interfacial surface between steel bar and concrete.

There were no significant differences between group 2 (300 kg cement/m$^3$) and group 3 (350 kg cement/m$^3$). However, when used a cement ratio of more than 400 kg (group 4 and 5), cement paste exhibits more bonding strength with a steel bar. In general, the load / Slip ratio increased when increased cement content, as seen in Figure 6. For smooth bar reinforcement curves, Figure 6-A there wasn’t a stable relationship due to the morphology of the interfacial zone, which has voids and aggregate contact along the effective length of steel bar. On the other hand, deformed bar curves show a more stable relation due to mechanical interlocking. These results can be used as a function to define the connection between the steel reinforcement and the concrete matrix when using the finite element program. This will help to show stress along the bonding area and leading to predict the maximum stresses (failure) before it’s occurring in critical zones.

4. Conclusion

During this investigation, the aim was to assess the effect of cement content on the properties of fresh and hardened concrete. Slump value increased when increased cement content (cement paste) which can increase the lubrication between aggregate particles. Using more than 400 kg of cement content made no significant increase in compressive strength. While the bonding strength increased even at 450 kg of cement for the two types of steel reinforcement (smooth and deformed). After 28 days of curing. The deformed bars demonstrated better bonding strength due to the mechanical interlocking between the cement paste and the bulges of steel bar. These bulges generate an additional resistance force to the strength of adhesion along the effective length (contact zone) inside the concrete sample.

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