# BOND STRENGTH OF CONCRETE WITH THE REINFORCEMENT BARS POLLUTED WITH OIL

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**Abstract:**

Practically, the concrete is usually cast in forms made from wood or steel. These forms are oiled to avoid their adhesion with the hardened concrete material. The reinforced steel bars may be polluted with the oil when they placed over or inside the forms. This pollution may affect the bond between the steel bars used and concrete and consequently the strength of reinforced concrete members will decrease. In present investigation, the bond strength of the oil polluted steel bars with concrete was studied. Tests were conducted on 72 cylindrical concrete specimens with compressive strength of 24 MPa at age of 28 days. Two embedded lengths of steel bars were considered in present tests namely 30 cm and 15 cm with four bar diameters. Based on the current experimental results, it is concluded that the pollution of steel bars with oil does not affect their bond strength if the embedded length of the bars is increased and their diameters are decreased. For these bars the bond strength is greater than the tensile strength. It is observed that the embedded length of the bar inversely affects the deterioration of the bond strength due to the bar pollution. For the polluted and non polluted bars it can be stated that small bar sizes has greater bond strength than large bar sizes if the embedded length is small. The predominant type mode of failure is splitting mode for all the tested specimens and no slip failure occurred in testing all the polluted and non-polluted bars throughout the experiments.

**Keywords:** Bond strength, polluted reinforcement, reinforced concrete

## Introduction

The transfer of axial force from reinforcing steel bar to the surrounding concrete produced from the development of tangential stress components along the contact surface. The stress acting parallel to the bar along the interface is called bond stress (Pillai & Kirk 1938, Hadi 2008). For the reinforced concrete material, it is necessary to create suitable bond between steel bars and surrounding concrete. Bond ensures that there is little or no slip of the steel bars relative to the concrete and the means by which stress is transferred across the steel-concrete (Hadi 2008, Warner et al 1998). Bond resistance is made up of chemical adhesion, friction and mechanical interlock between the bar and surrounding concrete. To avoid the adhesion of the hardened concrete and the constructional forms, the oil is widely used nowadays in the site constructions. This practical method may influence on the bond between the concrete and steel bars due to the pollution of steel bars by the oil before concrete casting.

The bond strength of the reinforcement steel with concrete was studied by many authors. Moetaz and EL-Hawary (1999) were studied bond strength properties of expoxy-coated steel reinforcement embedded in concrete with considering many pull-out tests. Bond strength degradation of steel bars and concrete under the effect of cyclic loading was measured by Cao and Chung (2001). The effect of different degree of corrosion for steel bars on the bond strength of concrete has been investigated by Fang et al (2004) and Fang et al (2006). Abdelbaky (2004) has been investigated the effect of rust removal agent on the bond strength of reinforcing steel bars. He had studied the effect of a new chemical agent developed by chemical companies called rust-stop or rust removal in removing the rust and its influence on the bond between reinforcing steel bars and concrete. His conclusions showed that the bond strength was reduced by a percentage of 7.6% when the bars coated with rust agent. Hadi (2008) had investigated the bond strength of high strength concrete with high strength reinforcement steel. He was used a concrete with compressive strength of about 70 MPa and a steel grade of 500 MPa. The conclusions were stated that the pull out specimens with smaller bar size has greater bond strength than that of the specimens with the large bar diameter. The test results also indicated that the initial stiffness increased as the amount of concrete surrounding the reinforcing bar increased. Foroughi et al. (2008) investigated the bond strength of the reinforcement steel bars in self-compacting concrete. They concluded that the self-compacting concrete specimens generated higher bond to reinforcing bars than the normal concrete specimens and the correlation between bond strength and compressive strength of normal concrete is more consistent. The bond strength of self compacting concrete and steel bars was studied also by Valcuende and Parra (2009) with depending on different parameters. Selvarag and Bhuvaneshwari (2009) studied the effect of applying different barrier coatings to the steel bars to protect them from corrosion. They had used four different coatings namely epoxy silicon-polymide used with two different pigments, polyester poly-aromatic isocyanate, and acrylic polyol-aromatic isocyanate. It has been concluded that the epoxy silicon polyamide resin based coating formulation shows good mechanical properties in addition to the barrier protection to the steel bars from corrosive environments. This conclusion agrees with the work results for Verma and Balasubramaniam (2011) in relation to the corrosion of steel reinforcement in concrete. They concluded that the structures exposed to deicing salts might benefit from the use of epoxy - coated steel bars. In another paper for Alengaram et al. (2010), a comparison has been made between the mechanical properties and bond properties of oil palm kernel shell lightweight concrete (OPKSC) and normal weight concrete (NWC). They concluded that the bond strength of (OPKSC) was found about 86% of the corresponding normal weight concrete and that there was no slip failure between (OPKSC) and reinforcement. Further, they showed that the experimental bond stress of (OPKSC) was 2.5 times higher than the stress calculated based on British standards. In 2010, bond tests for standard concrete beams have been conducted by Johnson (2010). He considered six types of reinforcement corrosion. The mechanical bond slope and initial bond stress were measured. It was demonstrated that the increasing in relative area of the steel bar ribs led to improve the initial bond strength. Assaad and Issa (2012) have been studied the bond strength of steel bars coated with epoxy and embedded in underwater concrete. Experimental works have been conducted and it was concluded that the ultimate bond stress is influenced by the washout loss level. The effect of accelerated corrosion on the bond strength of steel bars and concrete was investigated by Yalciner et al. (2012). The outcomes showed that due to the cracking of concrete during the test, the concrete specimens with high strength and corroded reinforcements gave higher degradation of bond strength.

According to the previous studies, it is demonstrated that the influence of oil pollution for steel bars on concrete strength has not been studied concisely so far. Thus, further investigations in this direction are considered essential. Present work includes the studying of the effect of polluted steel bars with the oil on the bonding stress between these bars and concrete material with taking into account many variables such as embedded length of steel bar, bar size and degree of pollution.

## Material and Method

### Main materials

The basic materials which used in preparation of concrete specimens for present experiments are as hereunder:

a- Ordinary Portland cement with the specific gravity of 3.10 and initial setting time of 105 minutes.

b- Local Iraqi sand from Al-Khazer area with the fineness modulus of 2.8.

c- Local Iraqi rounded gravel from Al-Khazer area with a maximum size of 25 mm.

d- Oil used for pollution of steel bars. The used oil is a mixture of kerosene with a percent of 33% and 66% of lubricant oil. The specific gravity for present oil is 0.87.

e- Deformed steel bars, where the tensile strengths for these bars were measured (as given in Table 1) before using them in the bond tests.

More specific properties for the main material which used in current specimens are given in Table 2.

According to the properties of materials used, concrete mix is designed to cast all the specimens. Present designed mix proportions are listed in Table 3.

### Preparation of specimens

A total of 72 pull out cylindrical specimens were made in two main groups. Each group consists of 36 specimens (Fig. 1). The first group (Group1) includes of specimens with embedded bars of 30 cm length and the second group (Group2) comprises samples with embedded bars of 15 cm length. For each group, the variables tested were bar diameter and the degree of the pollution of the steel bar. Four bar diameters were adopted namely 10, 12, 16, and 20 mm. While, the surface area of the embedded bars was polluted by coating them with the oil by a brush in three degrees which are as follows:-

1-No pollution- denoted as (0% poll.)

2-Half of the embedded surface area is polluted longitudinally - denoted as (50% poll.)

3- Entire embedded surface area is polluted longitudinally - denoted as (100% poll.)

These three cases of pollution of steel bar are depicted in Fig. 2.

For each variable studied in present research, three identical specimens were tested with using the same mixing, curing and testing conditions. The details of the considered parameters or variables which depended in current experimental investigation are listed in Table 4.

Before pouring the concrete in the moulds of pull out test, the internal surfaces of these moulds were oiled and the bottom of the concrete was isolated from the moulds by a cylindrical sheet made from cork with a hole at center of concrete specimen base to fix the reinforcing bars vertically. The length of reinforcing steel bars is about 600 mm. Fresh concrete was poured into the mould in five layers for the specimens of 300 mm height and in two layers for the specimens of 150 mm height. Each layer was compacted by 25 blows using the standard compacting rod and later the concrete surface was smoothed. After 24 hours, the moulds were removed and the concrete specimens were cured in a water tank for 28 days.

Eight concrete cubes (two cubes per each bars diameter) with size of 15 cm were cast to measure the reference compressive strength of the hardened concrete employed in present specimen fabrication. The average compressive strength for these cubes is around 24 MPa.

**Pull-out testing**

A hollow hydraulic machine (Fig. 3) with maximum loading capacity of 30 ton was used to perform current bond tests. The load was applied with a rate of 2 kN/sec and distributed on the specimen surface by a square steel plate with size of 20 cm and a hole at the center. All the specimens were tested at age of 28 days. The schematic diagram for the test layout is shown in Fig. 4.

**Bond stress calculation**

Bond stress is calculated as average stress between the reinforcing bar and the surrounding concrete along the embedded length of the bar. In general, the bond stress corresponding to the maximum pull out load can be regarded as the bond strength or the ultimate bond. The criterion of ultimate bond strength is characterized by its clear definition and simplicity in bond strength interpretation (Hadi 2008, Soylev & Francois 2006, ACI Committee 2002). For uniform bond, the bond stress S can be expressed as:

$$S = Pmax / (\pi \times L \times d) \qquad (1)$$

Where

Pmax= maximum pull out load

d=diameter of the bar

L =Embedded bar length

Equation 1 was employed in present calculation of bonding stress between the embedded steel bar and the surrounding concrete for the specimen.

**Experimental outcomes**

Bond strength was calculated as the average stress with depending aforementioned equation 1. The ultimate load at the failure of each concrete sample was obtained too. It has been seen that the pull out test specimens failed in two modes of failure namely splitting failure of the specimen CSF and steel rupture failure SRF. Based on data given in Tables 5 and 6, it is demonstrated that there is no pullout (slip) mode occurred throughout the experiments and the splitting failure mode was predominant type of failure for the tested specimens. This means that the reinforcement steel pollution does not decrease the chemical adhesion and friction between the hardened concrete and the bars significantly. In addition to that the mechanical interlock between the bars and surrounding concrete is the most effective component in the bond strength for the deformed bars.

The effect of each parameter or variable considered in present study on the bond strength of concrete with the polluted steel bars used is given as hereunder:

a- Effect of the steel bar embedded length

Figs. 5 and 6 show the variation of bond strength of concrete with the steel bars of 15 cm embedded length and bars of 30 cm embedded length respectively. It was observed that the embedded length of the bar greatly affects the bond strength especially for bars of small diameter (i.e. 10 and 12mm in present tests) in specimens of 30 cm embedded length. In addition to that it was appeared that the failure mode was SRF in these specimens; which refer to that the bond strength is greater than the tensile strength of the steel bars. In general, it has been seen also that the bond strength decreases when the embedded length increases. For the full-polluted 16 mm bar diameter specimens with 30 cm embedded length, the decrease in the bond strength with respect to no polluted case was 6.88% while decreasing of 29% was observed for the same specimens of 15 cm embedded length as depicted in Figs. 7 and 8. In addition to that, the test results show that the maximum loss of 29% in bond strength for the 15 cm embedded bar length specimens occurred in the case of specimen G3; while the maximum loss in the bond strength of 30 cm embedded bar length specimens happened in the concrete sample D3 with the percentage of 16%. This indicates that the embedded length of the steel bar inversely influences the deterioration of the bond strength due to the bar pollution. From these test results of the non-polluted specimens, it can be said that the pull out specimens with small bar size and embedded length has greater bond strength than that of the specimens with the large bar size and embedded length.

b- Steel bar diameter influence

Fig. 5 shows the variation of the bond strength of 30cm specimens for all bar sizes. It is clearly shown that specimens of small bar diameters (i.e. 10 mm and 12mm) fail in SRF mode of failure; while the others were failed in CSF mode of failure. This due to that the bond strength between the concrete and the bars is greater than the tensile strength of the steel bars of 10 mm and 12 mm diameter for all pollution degrees of steel bars.

For the specimens of 30 cm bar embedded length with 16 mm and 20 mm diameters there is a decrease in the bond strength for all polluted bars whether they are half-polluted or full polluted, but there is no general trend for this decrease. The maximum bond loss of 16.04% occurs in the specimens of full-polluted bars with 20 mm diameter.

Fig. 6 illustrates that the maximum bond loss for the specimens of 15 cm embedded bar length is about 29% which occurs in specimens of full-polluted bars with 16 mm diameter and the minimum bond loss of 0.8% happens in concrete specimens of full- polluted bar with diameter of 10 mm.

For the half-polluted bars, the maximum bond loss of 19.73% occurs in the specimens with 12 mm diameter steel bar and the minimum bond loss of 6.36% takes place in concrete sampls of 20mm diameter bar as shown in Fig. 7.

It can be stated that the diameter of the bar greatly affects the variation of bond strength of the polluted bars with concrete when the embedded length of the bar is increased.

c- Effect of the pollution degree

Figs. 9 and 10 illustrate the variation of residual bond strength (i.e. subtraction of the bond strength loss from 100) with the bar pollution for specimens of 30 cm length and 15 cm length respectively.

According to these Figs., it can be seen that for specimens of 30 cm length the degree of pollution of small bars with diameters of 10 mm and12 mm does not change the bond strength. While for other diameters, there is an increase in the bond strength deterioration due to the increasing in the degree of pollution. For the tested specimens, the deterioration of the bond strength increases with increasing the degree of the bar pollution except for specimens that have bars of 10 mm diameter and 15 cm embedded length. The reason of this fact, is the incompatibility between the load and the small bearing area of 50% in which the load is immediately transferred to the unpolluted side of the bar which causing the bond failure. For specimens with length of 15 cm, the degree of pollution of bars also affects the strength loss for all bar diameters used except for 10 mm diameter. The maximum percentage of the residual bond strength of 100% occurs in specimens of 30 cm length reinforced with 10 mm and 12 mm bars for all the degrees of pollution. While the maximum percentage of the residual bond strength of 99.20% occurs in specimens of 15 cm length reinforced with 10 mm bar with pollution degree of 100%. From the test results, it is appeared also that the increasing in the degree of pollution for the steel bar increases the bond strength loss.

**Conclusions**

Based on the tests results of present experimental research, these conclusions have been drawn:

1- The pollution of steel bar with oil does not affect the bond strength if the embedded length of the steel bar is increased and the bar diameter is decreased.

2- The embedded length of the bar inversely affects the deterioration of the bond strength due to the bar pollution.

3- The predominant mode of failure is splitting mode of failure for all tested specimens.

4- For concrete samples of small embedded bar length, the mode of failure is SRF for small bar diameters; while the mode is CSF for large bar diameters.

5- For specimens of large embedded bar length, no general trend is observed for the relation between the deterioration of bond strength and the bar diameter of the polluted bars.

6- For concrete specimens of large embedded length, the bond strength of the small bars is larger than the tensile strength of the bars.

7- In general, the loss in bond strength increases when the degree of the bar pollution increases.

8- No slip failure occurs in testing all the polluted and non-polluted steel bars throughout current bond tests.

9- For the polluted and non polluted steel bars, it can be stated that small bar sizes has greater bond strength than the large bar sizes if the embedded length is small.

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**Table 1: Properties of the used reinforcing bars**

| Nominal bar diameter (Ø) mm | Actual bar diameter (Ø) mm | Tensile strength MPa |
|---|---|---|
| 10 | 9.8 | 765.6 |
| 12 | 11.8 | 732.4 |
| 16 | 15.8 | 663.5 |
| 20 | 19.7 | 662.3 |

**Table 2: Characteristics of the materials used in present specimens**

| Properties | Amount | Unit |
|---|---|---|
| Gravel Absorption | 0.7 | % |
| Sand Absorption | 2.0 | % |
| Fineness Modulus | 2.8 | --- |
| Maximum aggregate size | 25 | mm |
| Cement Specific Gravity | 3.1 | --- |
| Gravel Specific Gravity | 2.65 | --- |
| Sand Specific Gravity | 2.7 | --- |
| Oil Specific Gravity | o.87 | |
| Gravel bulk Density | 1765 | $Kg/m^3$ |

**Table 3: Materials proportion of present designed concrete mix**

| Cement | Sand | Gravel | Water/Cement ratio |
|---|---|---|---|
| 1 | 1.78 | 3.31 | 0.55 |

**Table 4: Parameters and variables studied in this research**

| No. | Parameters | Variables | Amount |
|---|---|---|---|
| 1 | Embedded length (Embedded length) | 150 and 300 mm | 2 |
| 2 | Bar diameter (Ø) | 10,12,16 and 20 mm | 4 |
| 3 | Degree of pollution% (%poll.) | 0%,50% and 100% | 3 |
| Total number of the specimens = 2(groups) × 4(Ø) × 3(% of pull.) × 3 (Specimens)= 72 Specimens | | | |

**Table 5: Pullout test results for 30 cm with length around 30 cm**

| Item | poll. % | Ø mm | Bar embedded length mm | load KN | Failure mode |
|---|---|---|---|---|---|
| A1 | 0 | 9.8 | 300 | 56.70 | SRF |
| A2 | 50 | 9.8 | 301 | 56.60 | SRF |
| A3 | 100 | 9.8 | 302 | 60.40 | SRF |
| B1 | 0 | 11.8 | 302 | 80.38 | SRF |
| B2 | 50 | 11.8 | 300 | 83.14 | SRF |
| B3 | 100 | 11.8 | 300 | 81.26 | SRF |
| C1 | 0 | 15.8 | 303 | 110.54 | CSF |
| C2 | 50 | 15.8 | 303 | 109.46 | CSF |
| C3 | 100 | 15.8 | 302 | 102.60 | CSF |
| D1 | 0 | 19.7 | 302 | 131.73 | CSF |
| D2 | 50 | 19.7 | 300 | 120.12 | CSF |
| D3 | 100 | 19.7 | 300 | 109.86 | CSF |

**Table 6: Pullout test results for specimens with length around 15 cm**

| Item | poll. % | Ø mm | Bar embedded length mm | load KN | Failure mode |
|---|---|---|---|---|---|
| E1 | 0 | 9.8 | 148 | 50.50 | CSF |
| E2 | 50 | 9.8 | 151 | 43.18 | CSF |
| E3 | 100 | 9.8 | 150 | 50.77 | CSF |
| F1 | 0 | 11.8 | 150 | 80.49 | SRF |
| F2 | 50 | 11.8 | 152 | 65.47 | CSF |
| F3 | 100 | 11.8 | 150 | 61.87 | CSF |
| G1 | 0 | 15.8 | 153 | 74.47 | CSF |
| G2 | 50 | 15.8 | 148 | 60.37 | CSF |
| G3 | 100 | 15.8 | 151 | 51.78 | CSF |
| H1 | 0 | 19.7 | 147 | 60.72 | CSF |
| H2 | 50 | 19.7 | 150 | 58.02 | CSF |
| H3 | 100 | 19.7 | 151 | 53.37 | CSF |

**Fig. 1a: Concrete samples for a group**

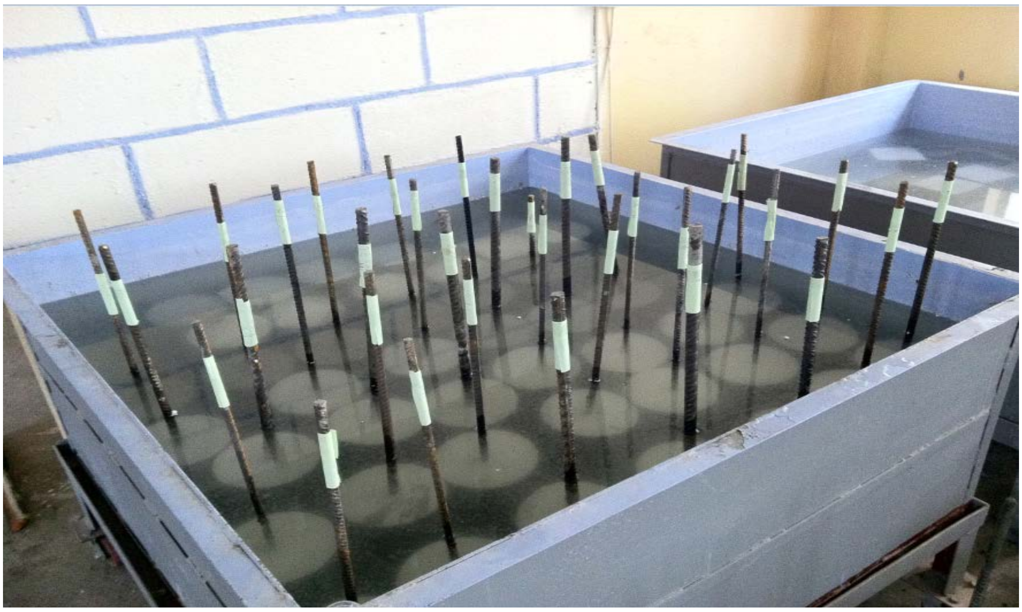
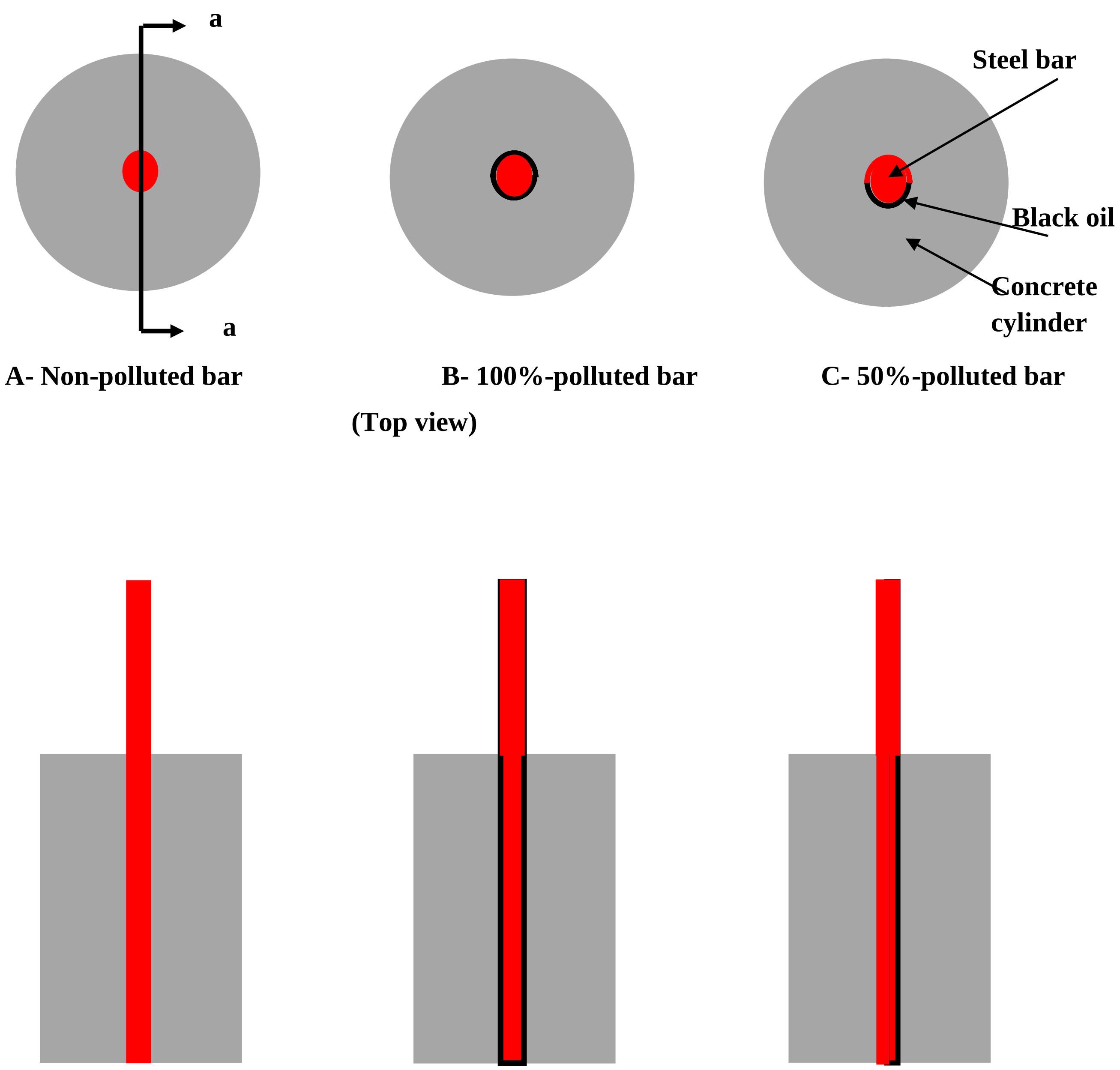


**Fig. 1b: Curing of the specimens**

**Fig. 1: Preparation of present concrete specimens used in pullout tests**




**(Section a-**

**Fig. 2: Cases of steel bar oil pollution**

**Fig. 3: Poll-out test specimen and loading machine**

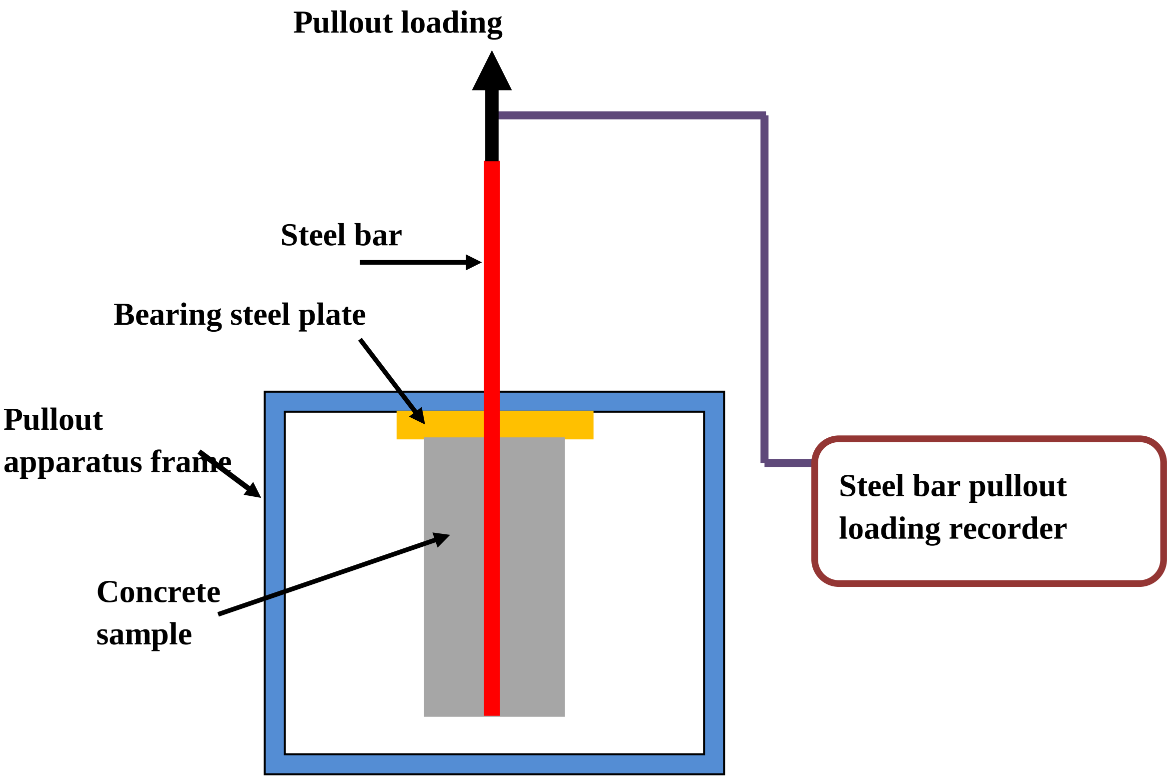



**Fig. 4: Schematic layout of present bond stress test**

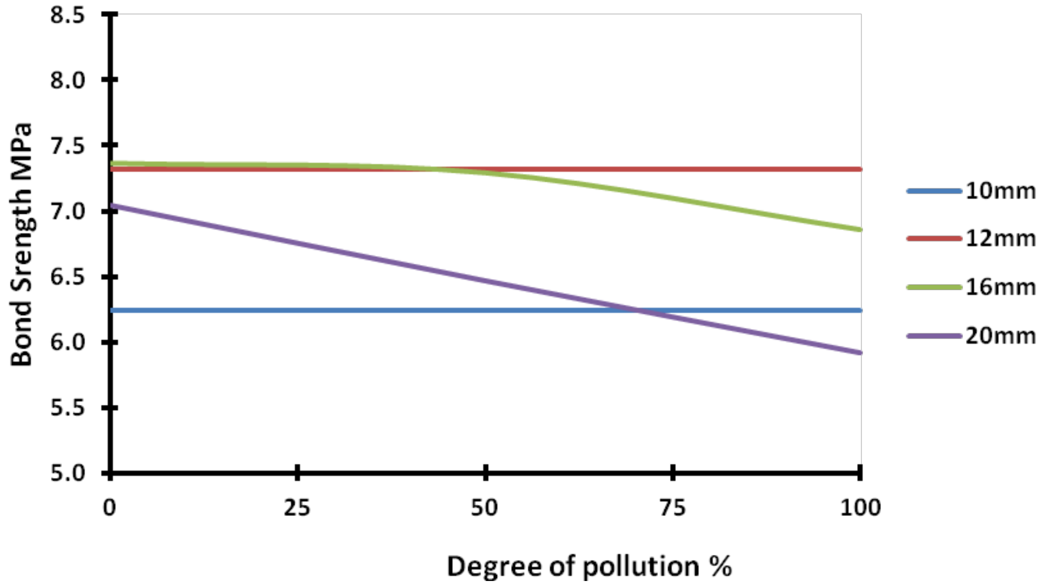



**Fig. 5: Average bond strength of concrete with bars of 30 cm length**

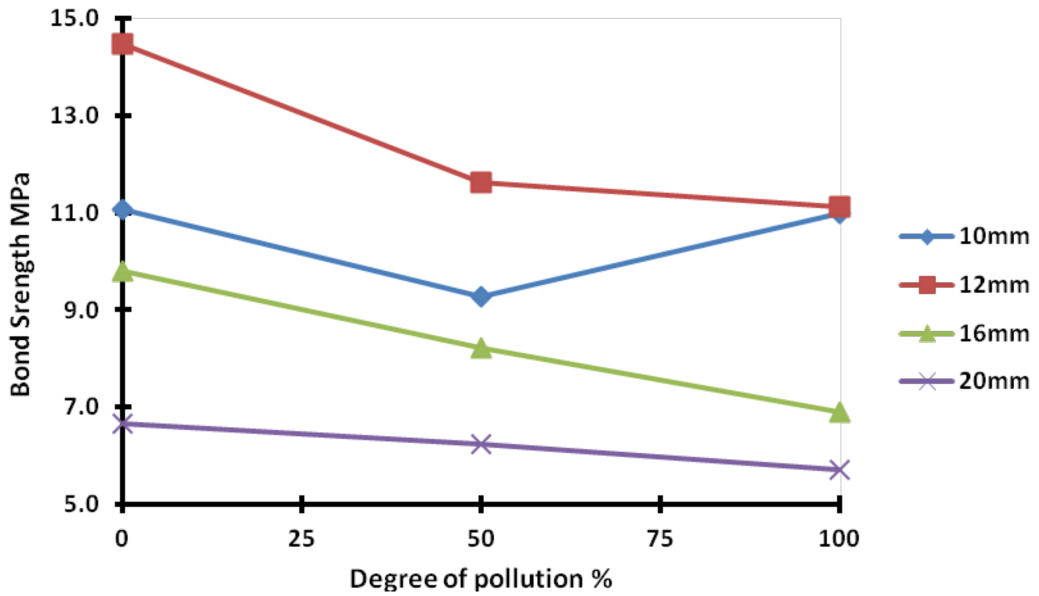



**Fig. 6: Average bond strength of concrete with steel bars of 15 cm length**

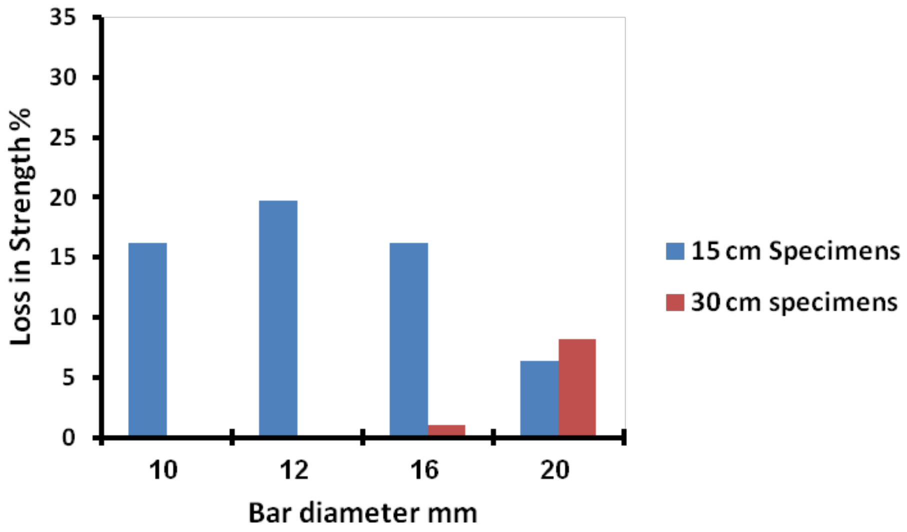



**Fig. 7: Average loss of bond strength due to 50% steel pollution**

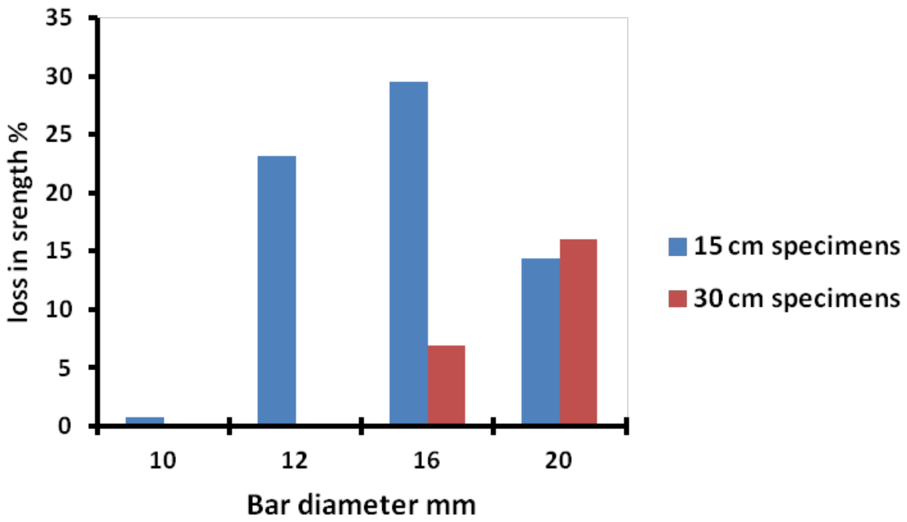



**Fig. 8: Average loss of bond strength due to 100% steel pollution**

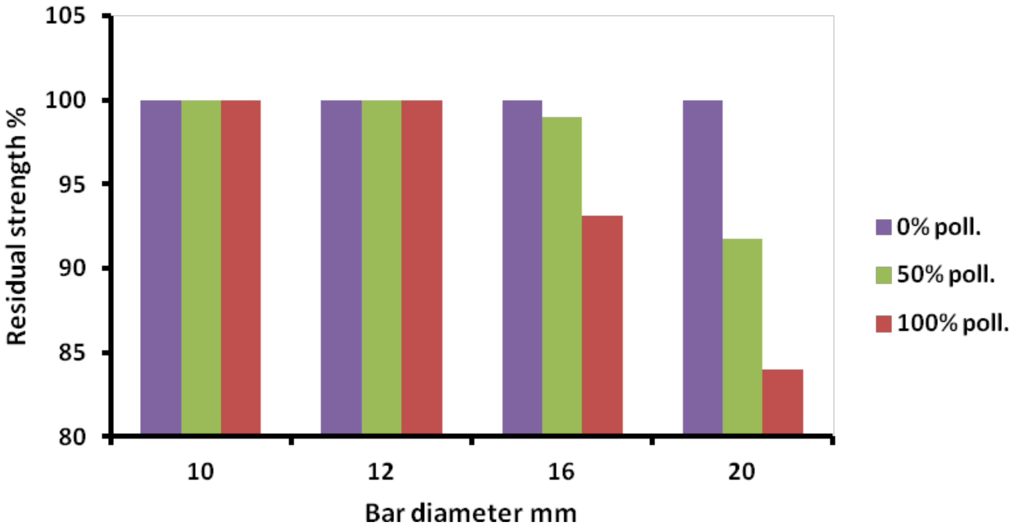



**Fig. 9: Variation of residual bond strength with bar pollution for specimens of 30 cm length**

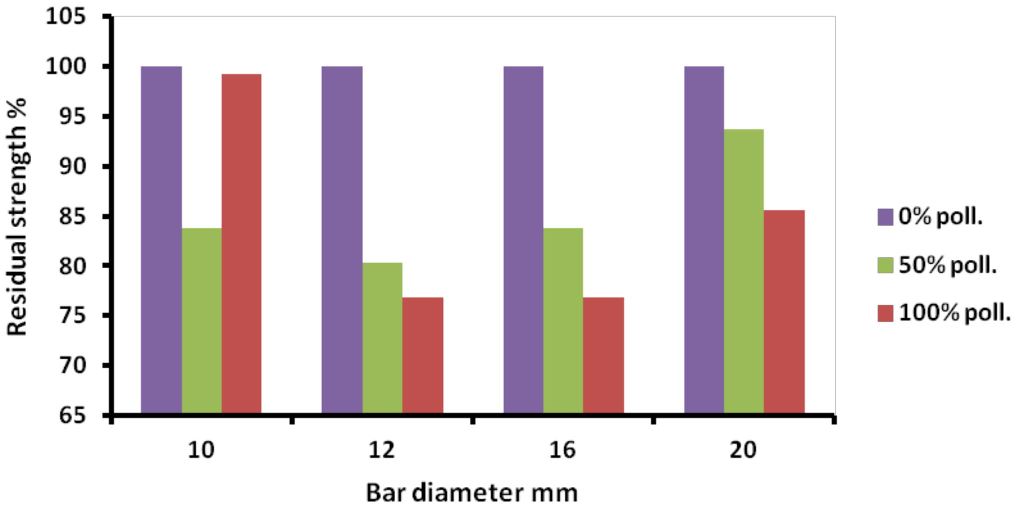



**Fig.10: Variation of residual bond strength with bar pollution for specimens of 15 cm length**