Mansoura Engineering Journal, (MEJ), Vol. 29, No. 2, June 2004. C. 73

The Effect of Rust Removal Agent on Bond Strength of Reinforcing Steel Bars

تأثير طرق إزالة الصدأ على قوة تماسك حديد التسليح

Sayed Abdelbaky

Associate professor, Housing & Building Research Center, Cairo, Egypt

ملخص :

عـندما يحدث صدأ لحديد التسليح داخل الخرسانة، فإنه يصبح من الصعب وقف عملية الصدأ بدون استخدام أى من طرق حماية أسياخ التسليح ضد الصدأ. أحد هذه الطرق هو إزالة الخرسانة المحتوية على كلوريدات من حول أسياخ التسـليح تم تنظيف الأسياخ باستخدام الرماله لإزالة الصدأ. وتعتبر عملية إزالة الصدأ باستخدام الرماله غير سهله خصوصاً إذا استخدمت فى الأماكن المغلقة حيث أنها تسبب تلوث كبير وأحياناً اختناق للعمال . وقد اتجهت الشركات المنـتجة للمواد الكيميائية المستخدمة فى الخرسانة لإنتاج مادة كيميائية لإزالة الصدأ تسمى مزيل الصدأ أو محول الصـدأ . حيث تقوم هذه المادة عند دهانها على حديد التسليح بتحويل أكسيد الحديد إلى مادة سوداء متزنة تلتصق علـى أسياخ التسليح مكونة طبقة رقيقة. وبناء على ذلك يهدف هذا البحث إلى دراسة تأثير هذه المادة على حماية حديد التسليح عند تعرضه لوسط مهاجم وكذلك تأثير هذه المادة على مقاومة التماسك بين الخرسانة وحديد التسليح عند دهان حديد التسليح بهذه المادة فقط أو بهذه المادة وكذلك الإيبوكسى الغنى بالزنك . وقد تم إجراء اختبار البلل والجفاف على أسياخ مدهونة بمحول الصدأ وأخرى غير مدهونة ثم إجراء الفحص البصرى . كذلك تم إجراء اختبار الاقـتلاع لأسياخ مدفونة داخل اسطوانات خرسانية واختبار الانحناء لتحديد مقاومة التماسك بين الخرسانة والأسياخ المدهونة بمادة المزيل و/أو الإيبوكسى.

ABSTRACT

When reinforcing bars start corroding inside the concrete, it is difficult to arrest the corrosion process without using any technique to protect the reinforcing bars against corrosion. One of these techniques, is removing the contaminated concrete around steel bars and cleaning them by using sand blast to remove the rust. Sand blast is not easy to use especially in closed areas where it results in high pollution and may cause suffocation to workers . Thus, a chemical agent was developed by chemical companies, called rust – stop or rust removal to clean the corroded reinforcing bars instead of sand blast.

The purpose of this research is to study the efficiency of the new material in removing the rust and its influence on the bond between reinforcing steel and concrete. The parameters studied in this research are the type of the chemical agent according to the chemical composition of each company, the compatibility with the epoxy coating and the efficiency of this material in protecting steel bars against aggressive media. Pullout and flexural tests have been carried out and visual inspection was recorded and discussed to determine the effect of the rust removal agent on the bond strength.

Key words: Rust removal, bond, reinforcing bars, concrete

Accepted June 30, 2004.

INTRODUTION

Corrosion of reinforcing steel bars is considered the most critical factor affecting the durability of concrete structures. Reinforcing bars can corrode before being placed in concrete, for any reason, through out the period of construction when the steel reinforcement is being exposed to aggressive environment without any protection or inside concrete due to the chloride ingress. Once the reinforcing bars start corroding inside the concrete, it is difficult to stop the process and hence the safety, load capacity and design life of the structure are significantly reduced with time. Previously, several investigations have been performed to study various techniques for protecting the reinforcing bars against corrosion and their effect on the bond strength between the reinforcing bars and concrete (1-9). Examples of these techniques are coating with epoxy, cathodie protection method, desalination method, realkalisation method and corrosion inhibitors . In case of epoxy coating which is the most commonly method used to protect steel bars, rust and scales must first be removed around steel bars using sand blast, then the epoxy is applied to eover the steel bars. The method of removing rust in this case is difficult and causes high pollution and also may causes suffocation to workers in closed areas. A chemical product was developed by chemical companies, called rust – stop or rust removal, it reaets with the iron oxide, converting it into a stable chemical compound (10).

The purpose of this research is to study the efficiency of the rust removal material in removing the rust and its influence on the bond strength between steel bars and concrete. The pullout and flexural tests are used to evaluate the bond strength.

2.EXPERIMENTAL PROGRAM

2.1 Test Specimens

To achieve the objective of this research, the test program was divided into four phases. The first phase is weighing the group of different diameters of corroded steel bars before and after brushing the rust converter to show if there is a loss or increase in the weight and to inspect the steel bars surface after brushing the rust converter. The second phase is to immerse steel bars brushed with rust converter and others without rust converter in saturated sodium chloride solution, at ambient temperature for two weeks. The concentration of the salts in solution was 30000 p.p.m. Wetting / drying cycles were repeated day after day for two weeks and visual appearance was monitored. The third phase is the pullout test to determine the bond strength. A total of 30 pullout specimens were tested in ten groups. Each group consists of three specimens (15×30 cm cylinder) with an embedded deformed steel bar of 10 mm diameter at the center of the specimens. The details of the studied parameters are shown in Table (1). The fourth phase consists of five group. The specimen used in this phase is shown in Fig. (1), which illustrates the configuration and dimensions of the test specimen. The specimen is a flexural beam separated in the middle with the reinforcing bar (10 mm diameter) crossing the gap. This test is preferred over a direct pullout test because it is more realistic and simulates the actual condition in beams or slabs. The details of the parameters of this phase are shown in Table (2).

2.2 Materials

Concrete was made of OPC, sand and crushed stone (dolomite). The mix proportions, by weight, for a cubic meter which were used to cast all the test specimens were,

Cement :	dolomite	: sand	: water
350 kg	1180 kg	590 kg	180 liter

The compressive strength of concrete after 28 days was 440 kg/cm^2.

Zinc-epoxy anti-corrosion coating, which is commercially applied in accordance with ASTM A 775 96, is used to coat the steel bars after removing the rust .

Rust stop or rust removal (also called rust converter) is primers with beige colour designed to be applied directly to a rusty surfaces. There are two primary components in a rust converter (10), a tannin (usually in the form of tannic acid) and an organic polymer. The organic polymer provides a protective primer layer since the conversion reaction occurs faster in an acidic environment. The tannin is the heart of a rust converter. It reacts with iron oxide, converting it to iron tannate, a stable blue/black corrosion product. This type is that used in this research. Rust converters are simple to use, they can be brushed or sprayed on the surface of the steel (the surface must be clean and dust free). Within 20 minutes after application, the converter will turn any rust it touches into coal black. The reaction is completely cured after 24 hours or longer if the ambient humidity exceeds 75% to 80% . Rust converters are formulated to be used as primers. Unlike traditional coatings, they must not be sanded and they should always be followed with a compatible topcoat (10). Two types of rust converters have been used in this program .

2.3.Specimens Preparation and Testing

First, corroded steel bars of length 60 cm were prepared. According to the test program indicated in Tables (1 & 2) the rust is removed using rust converter or wire brush, where the rust changed to a black layer immediately after brushing with rest converter as shown in Fig. (2). Within 20 to 30 minutes, this layer becomes dry. After 24 hours, some of these bars were coated with zinc-rich epoxy or other layer of rust converter and the others were uncoated. Then, the steel bars were placed in the mould of pullout or flexural test and the concrete was cast. Twenty four hours after casting, the moulds were removed and the specimens were cured in water for 28 days, then they were left in lab environment until the date of testing after three months. The steel bars of the first and second phases were prepared as above. The ultimate loads for pullout test groups were recorded at the first slip or at 0.25 mm slip, which ever smaller. The flexural beams were tested under central load, and the load corresponding to the first slip of the steel bar was recorded where it represents the bond failure load.

3.TEST RESULTS AND DISCUSSION

3.1 Visual Inspection

A group of corroded steel bars consists of 72 pieces with diameters of 10, 12, 16 and 18 mm is weighed before and after applying the rust converter. It was found that by applying the rust converter (rust removal), the colour of the steel bars changed in a few seconds to the black colour consisting of a very thin protective primer layer. The increase in the weight of steel bars after brushing with rust converter ranged from 0.20 to 0.80 % . Twenty four hours after applying the rust converter, a group of steel bars coated with one and two layers of rust converter and other uncoated, is exposed to wetting/ drying cycles in salted solution for two weeks. It is observed that the rust is existed over the whole length of the uncoated bars, while spots of rust was found on the bars coated with one layer which may appear at the weak points of painting, on the other hand, there are no traces of rust on the bars coated with two layers as shown in Fig. (3). Also, to study the efficiency of this layer when the steel bars embedded into the concrete, after the pullout tests were performed the specimens were split and inspected. It is observed that for all specimens having steel bars coated with one or two layers of rust converter, these layers were torn due to the pullout of bars but the colour of steel bars is still black and there are no traces of rust existence along the embedded length of the bars. On the other hand, there is no change on the surface condition of the embedded length of steel bars coated with rust converted and zinc-epoxy. While with respect to the bars where the rust is removed by wire brush, the rust is appeared once again along the steel bars. The details of the results are shown in Table (3).

3.2 Bond Strength Results

3.2.1 Pullout Test Results

Bond stress is calculated as the average stress between the reinforcing bar and surrounding concrete along the embedded portion of the bar. Table (4) indicates the type of failure of pullout tests for each variable. It is shown from the table that the failure type of the tested specimens in the pullout test is not constant for all the studied variables. For corroded bars coated with one or two layers of the rust converter and followed with, or without, epoxy coating, the failure was due to the free end bars slip. But for specimens having uncorroded bars, whether coated with rust converter only or rust converter and epoxy coating, the failure was due to the fracture of steel bars outside the concrete cylinder. At the same time, no readings of dial gage was recorded at the free end. This may be due to the increase of shearing force which is generated at the ribs of uncorroded bars compared with that generated in case of corroded bars. In both cases of failure, the ultimate loads obtained at the failure of each specimen are used to calculate the bond strength.

Figures (4a, b, c & d) show the effect of the investigated different parameters on the values of bond strength. Fig. (4a) shows the effect of rust removal method on the bond strength values. It is observed from the figure that the bond strength value for the specimen CB (rust removed by wire brush) and CA (rust removed by rust converter) is 48.7 and 45 kg/cm^2, respectively where the reduction between them is 7.6 %. For specimen PA (uncorroded bar coated with rust converter) where the failure was due to the fracture of steel bars, the bond strength value is 60.6 kg/cm^2. The higher value of this specimen compared with the values of specimens CB and AC is due to the corrosion of steel bar ribs for these specimens than specimen PA. The bond strength values for specimens CB, CA and PA after coating with zinc-rich epoxy which is denoted by CBZ, CAZ and PAZ are 48, 47 and 58.8 kg/cm^2, respectively. The difference between the bond strength values of these specimens and the corresponding values of specimens without epoxy coating is insignificant as shown in Figs. (4a & b). The bond strength values of specimens CAA (coated with two layers of rust converter) and CAAZ (coated with two layers of rust converter and one layer of epoxy) are 37.5 and 46.7 kg/cm^2, respectively compared with the value of 45 kg/cm^2 recorded for the specimen CA which is coated with one layer as show in Fig. (4c). Fig. (4d) shows the effect of rust converter types on the bond strength values, where the difference between the two corresponding values is insignificant whether for specimens coated with rust converter or coated with rust converter and epoxy. In general, from this discussion one can extract that the values of bond strength of coated bars with rust converter as a rust removal does not significantly affect in all the investigated parameters compared with the value obtained for the specimens having corroded bars, where the rust is removed by wire brush.

3.2.2 Flexural Beam Test Results

Five groups of flexural beams are chosen and tested to determine the realistically bond strength. Table (5) and Fig. (5) show the values of the bond strength results. The results indicate that the bond strength values of corroded bars, where rust is removed by wire brush as in specimen BB then coated with zinc-epoxy as in specimen BBZ, are 23 and 21 kg/cm^2, respectively. These values represent 0.92 and 0.84 of the value recorded for specimen with uncorroded bar, BP, .

The same behavior is observed for specimen BA (corroded bar coated with rust converter) and specimen BAZ (corroded bar coated with rust converter and zinc-epoxy) where the ratio between the bond strength values of these specimens and that one of specimen BP is 0.88 and 0.90, respectively. This means that, the difference between the bond strength values of corroded bars coated with rust converter and zinc-epoxy and the value obtained for uncorroded bar ranges from 16 % to 12 % and this reduction is in agreement with others for the coated bars (7) when taking into consideration the corrosion of ribs which took place. It is also observed that the difference between the bond strength values of specimens having corroded bars, where the rust is removed by wire brush, and those using rust converter is insignificant.

4. CONCLUSIONS

The following conclusions are drawn from the experimental studies of this investigation :

1 –The rust removal agent (rust converter) exhibited a higher efficiency in removing the rust of steel bars. Where it reacts with iron oxide, converting it into iron tannate, a stable blue / black corrosion product within few seconds and it completely dries in 20 to 30 minutes.

2 –Rust converters can be used instead of sand blast or wire brush in removing the rust, they formulated to be used as primers, but they must not be sanded.

3 –In case of corroded bars having scales, these scales should first be removed, then the rust converter is applied.

4 –To get more protection for corroded steel bars, rust converter must be followed by epoxy coating.

5 –It is not recommended to use the rust converter for more than one layer.

6 –Bond strength is reduced by 7.6 % when bars are coated with rust converter, while this reduction is insignificant when the bars are coated with epoxy.

7 –The bond strength obtained from flexural beam test shows a reduction in the values for coated corroded bars by 12 to 16 % compared with that obtained for uncorroded bars.

REFERENCES

1 – YEHIA, N.A "Experimental study of bond between concrete and reinforcing steel bars coated for corrosion protection," Journal of Eng. and applied science., Vol. 42, No. 4 Aug. 1995, Cairo Univ.

2 - Rasheeduzzafar, Ali M. G. & Al-Sulaimani, G. J, "Degradation of bond between reinforcing steel and concrete due to cathodic protection current," ACI Materials J., V. 90, No. 1, Jan. – Feb. 1993, PP. 8 – 15.

3 – AL-Sulaimani, G. J., Al Mandil, M. Y., Basunbul, I. A. & Kaleemullah, M., "Effect of epoxy coating of reinforcing bars on their bond behavior with surrounding concrete," third inter. conference, deterioration and repair of reinforced concrete in the Arabian Gulf, 1989, PP. 369 – 380.

4 – Ghaffari, H. A., Choi, O. C., Darwin D. & Mccabe, S. L., "Bond of epoxy coated reinforcement : cover, casting position, slump and consolidation," ACI, struc. J, V. 91, No. 1, Jan. – Feb. 1994, PP. 59 – 68.

5 – Hamad, B. S., "Comparative bond strength of coated and uncoated bars with different rib geometries," ACI, Materials J., Vol. 92, No. 6, Nov. – Dec. 1995, PP. 579 – 589.

6 – Taber, L. H., Abdeldjelil, B. & Richardson, D. N., "Effect of reinforcing bar contamination on steel – concrete bond during concrete construction," Internet, WWW. Web – test. umr. edu.

7 – Abdullah, R. & Cairns, J., "Bond strength of epoxy coated reinforcement," third inter. conference deterioration and repair of reinforced concrete in the Arabian Gulf, 1989, PP. 353 – 367.

8 – ABDEL-BAKY, S., "Durability of concrete repair method using bonding chloride barrier and anti – corrosion agents," sixth inter. conference on deterioration of reinforced concrete in the Arabian Gulf, 2000, PP. 539 – 552.

9 – Algapry, A. A., "Chloride extraction from reinforced concrete," Master thesis, faculty of engineering, Port Said, Suez canal Univ., 2002.

10 – Jery cermack, "Rust converters," old house Journal, old house mechanic Nov. – Dec. 1998.

Table (1) : Details of Studied Parameters in the Pullout Tests

No	Specimen*	Specification of Specimen
1	CB	The rust of the bar is removed by the wire brush.
2	CA	The rust of the bar is removed by the chemical agent.
3	CBZ	The rust of the bar is removed by the wire brush, then the bar is coated with zinc-rich epoxy.
4	CAZ	The rust of the bar is removed by the chemical agent, then, the bar is coated with zinc-rich epoxy.
5	PA	The bar without rust (clean) but painted with chemical agent.
6	PAZ	The bar without rust (clean) but painted with chemical agent, then coated with zinc-rich epoxy.
7	CAA	The rust of the bar is removed by the chemical agent, after drying of this layer another layer is painted.
8	CAAZ	The bar of this specimen is cured as specimen CAA and then coated with zinc-rich epoxy.
9	CA2	This specimen is as specimen CA but using a chemical agent from another company.
10	CA2Z	This specimen is as specimen CAZ but using chemical agent prom another company

* each specimen consists of 3 cylinders.

Table (2) : Details of Bond Test Using Flexural Beam

No	Specimen*	Specification of Specimens
1	BP	Beam with one bar of 10 mm diameter where the bar without rust (uncorroded)
2	BA	Beam with one bar of 10 mm diameter where the rust of the bar is removed by the chemical agent.
3	BB	Beam with one bar of 10 mm diameter where the rust of the bar is removed by the wire brush.
4	BBZ	This specimen is as specimen BB and after removing the rust, the bar is coated with zinc-rich epoxy.
5	BAZ	This specimen is as specimen BA and after removing the rust, the bar is coated with zinc-rich epoxy.

* each specimen consists of 3 beams.

Table (3) : The Results of Visual Inspection

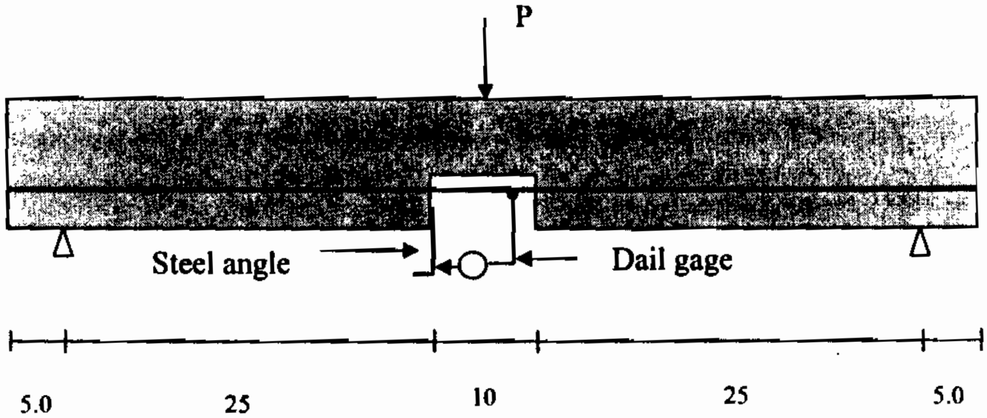
Specimen*	Visual observation
CB	There is a trace of rust spots in different locations along the steel bar
CA	The rust converter layer is torn as a layer but the colour of the embedded length of steel bar is black and there is no trace of rust along the bar.
CBZ	There is no change on the surface of the embedded length of coated steel bar (coating with epoxy)
CAZ	There is no change on the surface of the embedded length of coated steel bar (coating with one layer of rust converter and zinc-epoxy)
PA	The rust converter layer is torn as a layer but the colour of the embedded length of steel bar is black and there is no trace of rust along the bar.
PAZ	There is no change on the surface of the embedded length of coated steel bar (coating with one layer of rust converter)
CAA	The rust converter layer is torn as a layer but the colour of the embedded length of steel bar is black and there is no trace of rust along the bar.
CAAZ	There is no change on the surface of the embedded length of the coated steel bar (coating with two layers of rust converter and one layer of zinc-rich epoxy).
CA2	The rust converter layer is torn as a layer but the colour of the embedded length of steel bar is black and there is no trace of rust along the bar.
CA2Z	There is no change on the surface of the embedded length of the coated steel bar (coating with one layer of another type of rust converter and zinc-rich epoxy).
Flexural Beams	There is no change on the surface condition of the apparent part of steel bar which is coated with rust converter or zinc-rich epoxy.

Table (4) : Type of Failure of Pullout Test Specimen

No	Specimen	Type of Failure
1	CB	Two samples failed due to slipping and one due to the fracture of bar outside the concrete cylinder.
2	CA	The three samples failed due to the slipping of free ends of bars.
3	CBZ	Two samples failed due to slipping and one due to the fracture of bar outside the concrete cylinder.
4	CAZ	The three samples failed due to the slipping of free ends of bars.
5	PA	The three samples failed due to the fracture of steel bars outside the concrete cylinder.
6	PAZ	The three samples failed due to the fracture of steel bars outside the concrete cylinder.
7	CAA	The three samples failed due to the slipping of free ends of bars.
8	CAAZ	The three samples failed due to the slipping of free ends of bars.
9	CA2	The three samples failed due to the slipping of free ends of bars.
10	CA2Z	The three samples failed due to the slipping of free ends of bars.

Table (5) : Bond Strength Values Obtained From Flexural Beam Test

Specimen	Bond strength Kg/cm^2	Bond strength of corroded bar / Bond strength of BP
BP	25	1.0
BB	23	0.92
BA	22	0.88
BBZ	21	0.84
BAZ	22.5	0.90



Y= high tensile steel (36/52), Dimensions in cms
Cross section of the beam 10×10 cm

Fig. (1) Typical beam specimen for bond test

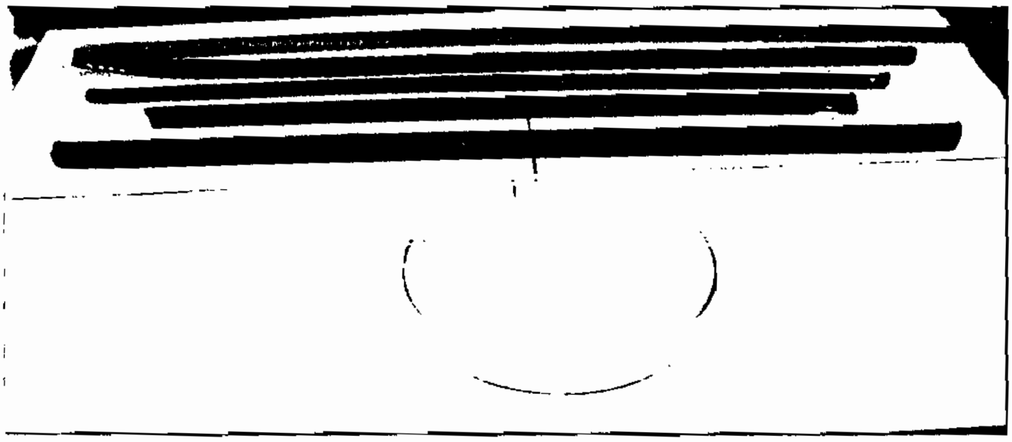


Fig (2) Corroded Steel Bars After Brushing With Rust Converter

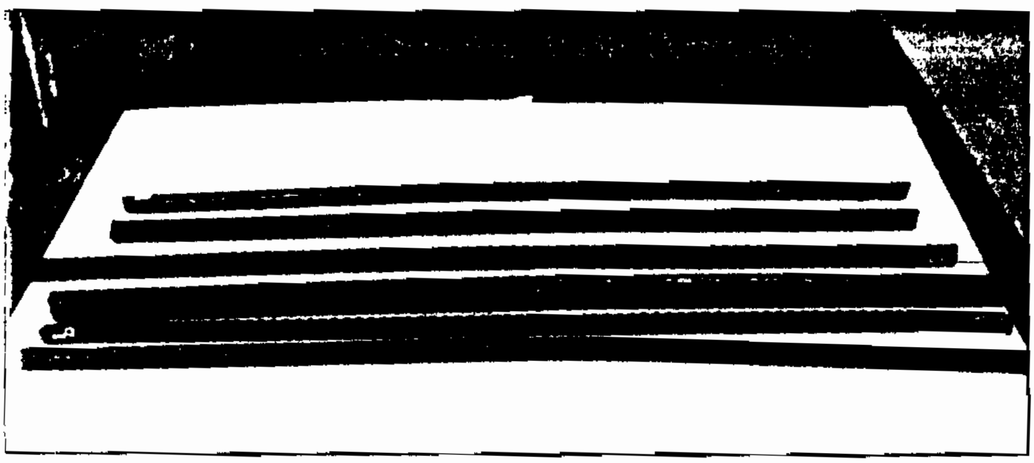


Fig (3) Steel Bars After Exposing to Wetting/ Drying Cycles in Salted Solution

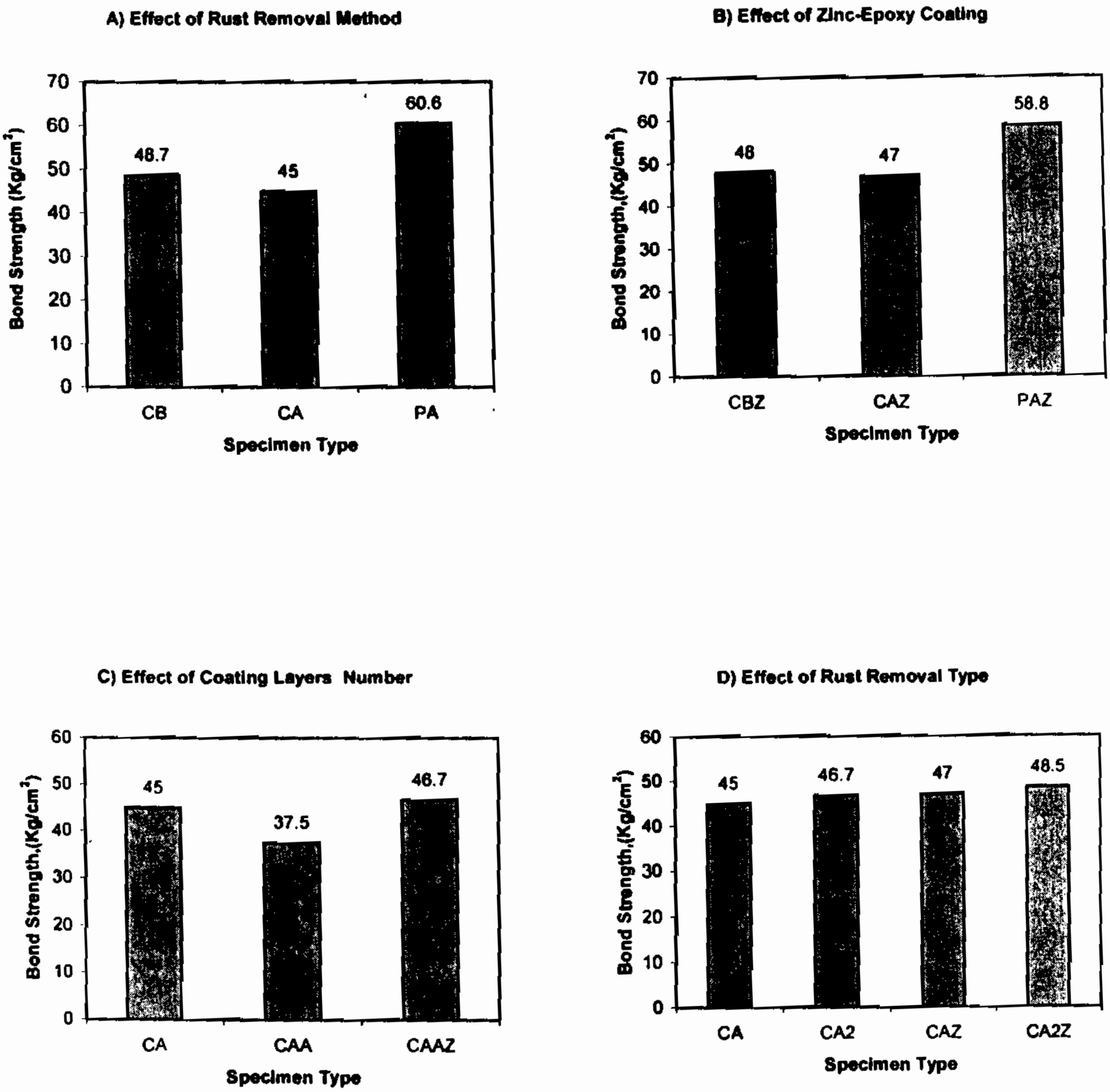


Fig.(4) The Values Of Bond Strength Obtained From The Pullout Tests For Different Parameters

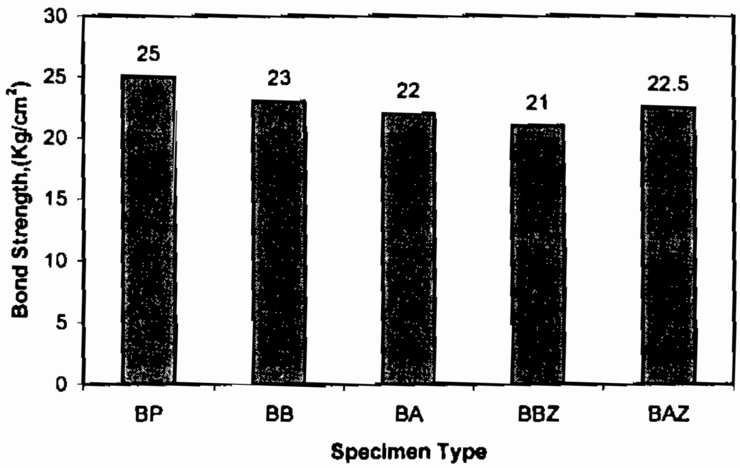


Fig.(5) Bond Strength Results Obtained From Flexural Beams Test.