Comparison of bond efficiency of various coating materials

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Abstract. The paper reports an experimental research investigation carried out to compare the bond resistance and efficiency of various coating materials, including epoxy, which were sourced locally. Thirty-four full size beams of varying lengths and sectional dimensions, with lap spliced bars in constant moment region were cast and tested in a four-point bending system. Three varying high yield diameter bars 16 mm, 20 mm and 28 mm were coated with various coating materials such as epoxy, chlorinated rubber, tyrolin, vinyl chloride and zinc ethyl silicate in an attempt to find a cheaper but effective coating material than epoxy. The ultimate moment from the tests were used to determine the stress developed in the steel rods. The bond efficiency, i.e. the ratio of test bond stresses and the theoretical bond stresses was used for the comparison of the various coating materials. The bond resistance and efficiency of vinyl chloride coated bars were found to be higher than that of epoxy and other materials, in all the beams tested. Statistically, there appear not to be significant difference between the bond efficiency of epoxy and vinyl chloride.

1. Introduction
Premature deterioration of reinforced concrete structures such as bridge decks, parking garages, sewage treatment and chemical plants, etc. has become a major problem. This early deterioration has been attributed to accelerated corrosion of reinforcing bars caused by chloride ions from de-icing materials and salts, Mathey and Clifton [1]. High humidity subjects exposed concrete structural elements to a perpetual state of wetness, especially during the rainy season. Water, in molecular or gaseous form, penetrates concrete and attacks the reinforcement causing corrosion, expansion and scaling of the steel rods. This phenomenon leads to cracking and spalling of concrete, reduction in diameter of reinforcement and subsequent reduction in strength of the structural elements, thus necessitating in many cases extensive repairs of structural elements. The situation is similar for concrete elements in permanent contact with water or de-icing materials e.g. water retaining structures, jetties etc.

Reinforced concrete is a dual structural arrangement with concrete mainly resisting compression forces and steel resisting the tensile forces. Its effectiveness as a structural member depends on the bond between steel reinforcement and concrete. Such effectiveness is reduced by corrosion which can be prevented or at least reduced by coating of reinforcing bars.

Of all the coating materials investigated and analyzed so far, only epoxy showed a good promise, Clifton and Mathey [2]. Epoxy coating has its own shortcomings besides being expensive, bond between concrete and epoxy coated steel rods is reduced. It is therefore desirable and worthwhile to investigate other materials such as chlorinated rubber, zinc ethyl silicate, vinyl chloride and tyrolin (cement and
sand mix) in an attempt to find cheaper and effective coating material that could possibly give higher bond strength.

2. Aims and objective
The major thrust of the investigation reported herein is to provide solutions to practical problems in reinforced concrete and hence contribute to knowledge and engineering practice on bond between concrete and steel reinforcement in high humid environment.

The specific objective of the work is to find other effective coating materials - effective in terms of bonding between concrete and steel that can be used to coat reinforcing rods instead of epoxy.

3. Design of Test Beams
Thirty-four full size beams were cast. Sixteen beams were cast for the preliminary investigation and eighteen beams for the confirmatory tests. The beams were of three sizes, 300 mm x 230 mm; 300 mm x 200 mm and 300 mm x 180 mm. The main bars were 28 mm, 20 mm and 16 mm diameter high yield bars. The depth of all beams was 300 mm while the length is a function of lap length and shear span thus length \( L = \ell + 300 \text{ mm} + 2a, +200 \text{ mm} \). The lengths varied with the bar diameters as 3.20 m, 2.90 m and 2.75 m respectively. The design of the beams is shown in Figure 1 and the beam data are shown in Table 1.

| Beam Name | b (mm) | Tensile Reinlt. A, (mm\(^2\)) | Lap Length +300mm | Shear Span \(a, (mm)\) | Beam Length (m) |
|-----------|--------|-------------------------------|-------------------|-------------------|----------------|
| A-U-10A   | 180    | 2T16 402 940 801             |                   |                   | 2.75           |
| A-U-10B   | 180    | 2T16 402 940 801             |                   |                   | 2.75           |
| A-U-1OC   | 180    | 2T16 402 940 801             |                   |                   | 2.75           |
| A-U-11A   | 200    | 2T20 628 1100 795           |                   |                   | 2.90           |
| A-U-11B   | 200    | 2T20 628 1100 795           |                   |                   | 2.90           |
| A-U-11C   | 200    | 2T20 628 1100 795           |                   |                   | 2.90           |
| A-U-12A   | 230    | 2T28 1232 1420 783         |                   |                   | 3.20           |
| A-U-12B   | 230    | 2T28 1232 1420 783         |                   |                   | 3.20           |
| A-U-12C   | 230    | 2T28 1232 1420 783         |                   |                   | 3.20           |
| A-E-1A    | 180    | 2T16 402 940 801           |                   |                   | 2.75           |
| A-E-1B    | 180    | 2T16 402 940 801           |                   |                   | 2.75           |
| A-E-1C    | 180    | 2T16 402 940 801           |                   |                   | 2.75           |
| A-E-2A    | 200    | 2T20 628 1100 795         |                   |                   | 2.90           |
| A-E-2B    | 200    | 2T20 628 1100 795         |                   |                   | 2.90           |
| A-E-2C    | 200    | 2T20 628 1100 795         |                   |                   | 2.90           |
| A-E-3A    | 230    | 2T28 1232 1420 783       |                   |                   | 3.20           |
| A-E-3B    | 230    | 2T28 1232 1420 783       |                   |                   | 3.20           |
| A-E-3C    | 230    | 2T28 1232 1420 783       |                   |                   | 3.20           |
| A-VC-16A  | 180    | 2T16 402 940 801         |                   |                   | 2.75           |
| A-VC-16B  | 180    | 2T16 402 940 801         |                   |                   | 2.75           |
| A-VC-16C  | 180    | 2T16 402 940 801         |                   |                   | 2.75           |
| A-VC-17A  | 200    | 2T20 628 1100 795     |                   |                   | 2.90           |
| A-VC-17B  | 200    | 2T20 628 1100 795     |                   |                   | 2.90           |
| A-VC-17C  | 200    | 2T20 628 1100 795     |                   |                   | 2.90           |
| A-VC-18A  | 230    | 2T28 1232 1420 783   |                   |                   | 3.20           |
| A-VC-18B  | 230    | 2T28 1232 1420 783   |                   |                   | 3.20           |
| A-VC-18C  | 230    | 2T28 1232 1420 783   |                   |                   | 3.20           |
| A-CR-22   | 185    | 2T16 402 940 801     |                   |                   | 2.75           |
| A-CR-19   | 200    | 2T20 628 1100 795    |                   |                   | 2.90           |
| A-ZS-20   | 185    | 2T16 402 940 801     |                   |                   | 2.75           |
| A-ZS-21   | 200    | 2T20 628 1100 795    |                   |                   | 2.90           |
| A-T-7     | 180    | 2T16 1402 940 801   |                   |                   | 2.75           |
| A-T-8     | 200    | 2T20 628 1100 795   |                   |                   | 2.90           |
| A-T-9     | 230    | 2T28 1232 1420 783  |                   |                   | 3.20           |

Beams are without stirrup over lap.
Side and bottom covers are 25 mm thick.
Beams are 300 mm depth.

![Figure 1. Typical beam without stirrup overlap.](image)

The beams contain tensile lap splices without transverse reinforcement over the lap. In all the beams 10 mm diameter high yield stirrup at 100 mm centres were provided in the shear span to resist shear failure. The lapped bars were placed in contact because this is the most probable on construction sites. The loading points were 150 mm from the lap ends thereby making the distance between the point loads to be \( \ell_s + 300 \) mm.

The ultimate anchorage bond length recommended in BS 8110: 1985 [3] was used as in equation (1)

\[
l_s = \frac{0.87 f_y \phi}{4 \beta \sqrt{f_{cu}}}
\]  

(1)

Failure mode in flexure is strongly dependent on the shear-span/effective depth ratio \( (a/d) \).

Based on experimental studies reported in Kong and Evans [4] the failure pattern to ensure flexural failure was used. \( a/d \) was taken as 3, hence \( a = 3d \).

The side and bottom covers to the lapped bars were made equal, \( c_s = c_b = c \) as failure will occur at the side with the minimum cover; hence the covers \( (c_s \) and \( c_b) \) to the beams were both 25 mm.

4. Preparation and Application of Coating Materials

The reinforcements were sand blasted to remove rust. Coating materials were sprayed on the steel rods in this investigation.

4.1. Epoxy zinc rich

Epoxy zinc rich is in two parts. Part A, base and Part B, which is the hardener. The parts were measured out by volume in ratio 3:1, as recommended in the manufacturer’s manual, and the two parts were thoroughly mixed together. Thinner was added until the mixture was light enough to pass through the nozzle of a conventional spraying gun. The lengths of the reinforcements to be coated were marked out. The mixture was then sprayed, in one coat, on the marked portions of the reinforcements and allowed to dry in the shade (without direct exposure to sunshine).

4.2. Vinyl chloride

Vinyl chloride is in different colours, the dull red colour was used for the preliminary tests and the light grey colour was used for the confirmatory tests. It was thoroughly mixed and fed into the spraying gun. Two coats were applied consecutively to achieve a uniform coverage.

4.3. Chlorinated rubber
This coating material is red in colour. Chlorinated rubber requires no thinner, the material was simply agitated thoroughly and fed into the spraying machine and only one uniform coat was applied.

4.4. Zinc ethyl silicate
Zinc ethyl silicate is in two parts (Part I, powder and Part II, liquid). The two parts were measured out in ratio 2:1 by weight. The two parts were thoroughly mixed together. No thinner was added. The mixture was sprayed, in one coat, on the marked portions of the reinforcements.

4.5. Tyrolin
Equal measure by weight of sand and cement was carried out, precisely, 2.902 kg of Grade 14 sand, 0.725 kg of Grade 25 sand totaling 3.627 kg sharp sand and 3.627 kg of cement were thoroughly mixed to achieve a uniform consistency; 2.00 kg of water was added and further mixed uniformly. The mix ratio by weight was 1.81:1.81:1.0 (sand:cement:water). The mixture was sprayed on the rods with the tyrolin spraying machine. The tyrolin sprayed rods were allowed to dry in the shade for seven days before the reinforcement cages were made.

5. Manufacture and test procedure of cubes and beams
Concrete used for the investigation was grade 35 with targeted cube strength of 35 N/mm². Concrete cubes were cast in batches and cured for 28 days in the laboratory. The strengths achieved at test are in Table 3. The reinforcement cages were put in the mould and concrete spacers were placed at interval at various locations; bottom and sides. The ready-mix concrete was poured and vibrated in the mould with poker vibrator. After demolding, the beams were cured by wetting at intervals for seven days.

5.1. Compressive strength of concrete cubes
The aim of the test was to determine the strength of concrete in the beams and to serve as a control so that the compressive strength reach at least the targeted value of 35 N/mm². The cubes were weighed on Avery weighing machine, 50 kg capacity and tested in the Avery Universal testing Machine of 100,000 kg capacity.

5.2. Beam Test
The beams were tested with a four-point bending arrangement with an I steel section as the spreader beam in a 100,000 kg capacity Avery Universal Testing Machine to determine the ultimate failure loads, modes and crack patterns. The load was gradually applied until the failure of the beam occurred. The failure load was recorded and analyzed as follows.

6. Analysis and discussion of test results
The steel stress developed in each beam was determined by analyzing the section using the general theory for ultimate flexural strength. The ultimate moment for each beam was obtained by applying the principles of statics. The lapped splice was in the constant moment region. The ultimate moment at the point load in Figure 1 is

\[ M_{ul} = \frac{q}{2} (a_u) \]  

From the equilibrium condition in Figure 2.
Cross section  \hspace{1cm} \text{Strain}  \hspace{1cm} \text{Stress and Forces}

\textbf{Figure 2.} Strain and Stress distribution at failure.

Hognestad’s stress was adopted and the characteristics $k_1$, $k_2$ and $\Sigma_{cu}$ were extracted from Kong and Evans [4] in Table 2.

\textbf{Table 2.} Characteristics of Hognestad Et-Al’s Stress Block.

\begin{center}
\begin{tabular}{cccc}
S/N & $f_{cu}$ (N/mm$^2$) & $k_1$ & $k_2$ & $\Sigma_{cu}$ \\
\hline
\textbf{(Preliminary)} & & & & \\
1. & 34.67 & 0.59 & 0.449 & 0.0034 \\
2. & 34.52 & 0.589 & 0.453 & 0.0034 \\
3. & 31.09 & 0.611 & 0.457 & 0.0034 \\
4. & 35.06 & 0.586 & 0.451 & 0.0033 \\
5. & 34.53 & 0.59 & 0.452 & 0.0034 \\
6. & 27.53 & 0.632 & 0.461 & 0.0035 \\
7. & 30.67 & 0.613 & 0.458 & 0.0034 \\
\textbf{(Confirmatory)} & & & & \\
8. & 36.47 & 0.581 & 0.450 & 0.0033 \\
9. & 34.44 & 0.594 & 0.454 & 0.0034 \\
10. & 37.90 & 0.575 & 0.450 & 0.0033 \\
11. & 36.98 & 0.578 & 0.449 & 0.0033 \\
12. & 38.70 & 0.574 & 0.449 & 0.0033 \\
13. & 33.30 & 0.596 & 0.456 & 0.0034 \\
14. & 30.44 & 0.614 & 0.457 & 0.0034 \\
\end{tabular}
\end{center}

\[ k_1 f_{cu} b x = A_s f_s. \]  

(3)

Taking moment about the compressive force, the ultimate moment of resistance is

\[ M_u = A_s f_s (d - k_2 x), \]  

(4)

from where:

\[ \frac{M_u}{bd^2} = \rho f_s - \frac{k_2 (\rho f_s)^2}{k_1 f_{cu}} \]  

(5)

The properties of the concrete stress block are expressed in terms of the characteristic ratio $k_1$ and $k_2$. Stress block proposed by Hognestad et-al reported in Kong and Evans [4] and universally accepted was used. Based on the mean cube strength, various values of $k_1$ and $k_2$ and $\Sigma_{cu}$ are tabulated in Table 2. The quadratic equation in (5) was solved yielding two values of $f_s$, one of which was always unreasonable because it is not practicable. The reasonable value was the stress developed in the steel.
6.1. Test Bond Stress, $\tau_t$

The bond strength is the average stress along the length of the splice.

From equilibrium

$$A_s f_s = \tau_t \pi \phi_s l_s,$$

from where:

$$\tau_t = \frac{f_s \phi_s}{4l_s}.$$  \hspace{1cm} (7)

The steel stress developed in each beam that was determined from equation (5) was substituted in (7) to obtain the $\tau_t$ ($\tau_{test}$).

6.2. Theoretical Bond Stress, $\tau_{cal}$

The theoretical bond stress, $\tau_{cal}$, was determined from a semi-empirical statistical regression equation developed by Orangun et-al [5].

For bars with no transverse reinforcement

$$\tau_{cal} = [1.2 + 3 \left( \frac{c}{d_b} \right) + 50 \left( \frac{d_s}{l_s} \right)] f_c^{1(0.5)}$$  \hspace{1cm} (8)

Equations (8) is in imperial unit and concrete cylinder strength. The expressions were converted to SI units and modified for use with concrete cube strength by Cairns and Abdullah [6] to give:

$$\tau_{cal} = [0.09 + 0.24 \frac{c}{d_b} + 3.9 \frac{d_s}{l_s}] \sqrt{f_{cu}}$$  \hspace{1cm} (9)

The bond strength equation in (9) proposed by Orangun et-al [5] was adopted as the formula for theoretical bond stress in this work. It formed the basis of the bond strength equation in the 1995 and 2002 American Concrete Institute (ACI) codes. Leet, Kenneth [7].

6.3. Bond Stress using BS 8110’s Recommendation, $\tau_{BS8110}$

The British Standard, BS 8110’s, 1997[8] recommended bond stress was also used to calculate the bond efficiency.

$$\tau_{BS} = \beta \sqrt{f_{cu}}$$  \hspace{1cm} (10)

with the factor $\beta$, taken as 0.5 because deformed bars were used in tension.

7. Discussion of test results

Comparison of Bond Efficiency of Various Coating Materials

The investigation of various coating material to compare their bond resistances and efficiencies was carried out in two phases: the preliminary and confirmatory tests. Preliminary tests were carried out using epoxy, vinyl chloride, chlorinated rubber, zinc ethyl silicate and tyrolin. All were locally sourced coating materials from the manufacturers. Three different bar diameters, T16 mm, T20 mm and T28 mm were used, one beam each was cast with each of the bar diameters. The beam data is shown in Table 1. The bond strength ratio $\tau_t/\tau_{cal}$ was plotted against the coating materials in Figure 3. As expected, uncoated bars gave a higher bond strength than coated bars, except in T28 diameter bars for vinyl chloride. This result is in line with previous research investigation reported in Mathey and Clifton [1],
Treece and Jirsa [9], Cuzen and Yu [10], Kayyali and Yeomans [11], Thangavel et-al [12], Yan and Mindess [13] that coating reduces bond strength.

Bond resistance has been found to reduce with larger bar diameter for uncoated bars, from Figure 3 it would appear that reduction due to coating has neutralized the effect of bar diameter. It is equally possible that the effect may not have shown because the coating thickness varied with the coating material.

Bars coated with tyrolin also gave a higher bond strength ratio than other coating materials for 20 mm diameter bars. Tyrolin (mixture of cement, sand and water) on its own is permeable and therefore cannot constitute a physical barrier to the oxygen and moisture necessary for the corrosion reaction. It can therefore, at best, be used to improve the bond strength of coated reinforcing bars by its mixture or application with other coating materials in sequence. The performance of bars coated with tyrolin is to be expected as dry tyrolin formed a rough surface with multiple grooves. These grooves are deeper than the regular rib pattern on the bar and this allows for better bond performance of the bars coated with tyrolin.

Vinyl chloride showed about the same performance with epoxy and of course a better bond performance than other tested materials on bar diameters T16 mm and T20 mm. Confirmatory tests were carried out on coatings which showed a good promise in the preliminary tests, that is, vinyl chloride and epoxy. Values plotted for chlorinated rubber and zinc ethyl silicate were only for one beam for each bar diameter as the two materials did not show good promise. Uncoated bars were also tested for comparison. Two beams each were further cast with 28 mm, 20 mm and 16 mm diameter high yield bars coated with vinyl chloride and epoxy. Table 1, Table 3 and Figure 3 show the beam data and the test results respectively.

![Figure 3. Comparison of bond efficiency of various coating materials.](image-url)
Table 3. Beam Test Results.

| Beam Name | $f_{cu}$ (N/mm$^2$) | $M_u$ (kN.m) | $f_i$ (N/mm$^2$) | $\tau_i$ (N/mm$^2$) | $\tau_{cal}$ (N/mm$^2$) | $\tau_{BS}$ (N/mm$^2$) | $\frac{\tau_i}{\tau_{cal}}$ | $\frac{\tau_i}{\tau_{BS}}$ | $\frac{\tau_{cal}}{\tau_{BS}}$ |
|------------|-----------------|--------------|-----------------|-----------------|-----------------|-----------------|----------------|----------------|----------------|
| A-U-10A    | 34.67           | 54.07        | 561.53          | 3.51            | 3.31            | 2.94            | 1.06           | 1.19           | 1.19           |
| A-U-10B    | 36.47           | 55.27        | 573.31          | 3.58            | 3.40            | 3.02            | 1.05           | 1.19           | 1.22           |
| A-U-10C    | 34.44           | 52.27        | 576.65          | 3.60            | 3.30            | 2.93            | 1.09           | 1.28           |                |
| A-U-11A    | 34.67           | 61.17        | 473.92          | 2.96            | 2.87            | 2.94            | 1.03           | 1.01           |                |
| A-U-11B    | 36.47           | 82.28        | 555.30          | 3.47            | 2.94            | 3.02            | 1.17           | 1.20           | 1.14           |
| A-U-11C    | 34.44           | 79.10        | 556.86          | 3.48            | 2.86            | 2.93            | 1.22           | 1.19           |                |
| A-U-12A    | 34.67           | 94.44        | 371.23          | 2.32            | 2.37            | 2.94            | 0.98           | 0.78           |                |
| A-U-12B    | 36.46           | 121.37       | 476.37          | 2.98            | 2.43            | 3.02            | 1.23           | 0.99           | 1.12           |
| A-U-12C    | 34.44           | 111.19       | 429.99          | 2.69            | 2.36            | 2.93            | 1.14           | 0.92           |                |
| A-E-1A     | 31.09           | 62.64        | 370.98          | 2.32            | 3.14            | 2.79            | 0.74           | 0.93           |                |
| A-E-1B     | 36.98           | 72.25        | 471.98          | 2.94            | 3.42            | 3.04            | 0.86           | 0.97           | 0.91           |
| A-E-1C     | 37.90           | 85.07        | 589.58          | 3.86            | 3.46            | 3.08            | 1.12           | 1.25           |                |
| A-E-2A     | 31.09           | 88.40        | 430.12          | 2.69            | 2.72            | 2.79            | 0.99           | 0.96           |                |
| A-E-2B     | 37.90           | 113.45       | 539.32          | 3.89            | 3.37            | 3.08            | 1.12           | 1.26           | 1.08           |
| A-E-2C     | 36.98           | 92.38        | 450.38          | 2.83            | 2.96            | 3.04            | 0.95           | 0.91           |                |
| A-E-3A     | 31.09           | 125.44       | 384.79          | 3.37            | 2.46            | 2.79            | 1.07           | 0.86           |                |
| A-E-3B     | 37.90           | 142.86       | 452.73          | 2.83            | 2.47            | 3.08            | 1.14           | 0.92           | 1.04           |
| A-E-3C     | 36.98           | 122.70       | 358.61          | 2.24            | 2.44            | 3.04            | 0.92           | 0.74           |                |
| A-VC-16A   | 34.53           | 40.05        | 403.32          | 2.52            | 3.31            | 2.94            | 0.76           | 0.86           |                |
| A-VC-16B   | 38.70           | 55.27        | 569.82          | 3.56            | 3.50            | 3.11            | 1.02           | 1.14           | 0.95           |
| A-VC-16C   | 33.30           | 53.67        | 560.34          | 3.50            | 3.25            | 2.89            | 1.08           | 1.21           |                |
| A-VC-17A   | 34.53           | 64.40        | 437.19          | 2.73            | 2.86            | 2.94            | 0.95           | 0.93           |                |
| A-VC-17B   | 38.70           | 76.32        | 550.34          | 3.44            | 3.03            | 3.11            | 1.13           | 1.11           | 1.09           |
| A-VC-17C   | 33.30           | 101.92       | 537.15          | 3.36            | 2.81            | 2.89            | 1.19           | 1.16           |                |
| A-VC-18A   | 38.70           | 125.28       | 488.67          | 3.05            | 2.50            | 3.11            | 1.22           | 0.98           |                |
| A-VC-18B   | 33.30           | 126.06       | 519.12          | 3.24            | 2.32            | 2.89            | 1.40           | 1.12           | 1.34           |
| A-VC-18C   | 30.44           | 119.80       | 496.04          | 4.10            | 2.22            | 2.76            | 1.40           | 1.12           |                |
| A-CR-19    | 27.53           | 51.68        | 384.68          | 2.18            | 2.56            | 2.62            | 0.85           | 0.83           |                |
| A-ZS-21    | 30.67           | 58.43        | 396.49          | 2.48            | 2.70            | 2.77            | 1.92           | 0.89           |                |
| A-T-7      | 35.06           | 47.25        | 483.16          | 3.02            | 3.33            | 2.96            | 0.91           | 1.02           |                |
| A-T-8      | 31.09           | 77.91        | 556.40          | 3.48            | 2.72            | 2.79            | 1.28           | 1.25           |                |
| A-T-9      | 35.06           | 99.44        | 571.39          | 2.32            | 2.58            | 2.96            | 0.98           | 0.78           |                |

As was expected, uncoated bars were confirmed to give higher bond efficiency than coated bars for all the bar diameters investigated. Vinyl chloride surprisingly gave a better average bond strength ratio in all the bar diameters tested as in Figure 3. Epoxy and vinyl chloride are both manufactured locally, although, some of the key components may have been imported. Vinyl chloride and its thinner are cheaper. Vinyl chloride gave a higher bond resistance in all the bar diameters for 16 mm, 20 mm and 28 mm respectively.

7.1. Coating factor, $\beta_i$
Because the beams were not cast in the same batch, the concrete strength variation was eliminated by multiplying the obtained splice strength with $\frac{35}{f_{cu}}$. In previous studies Mathey and Watsein [14], Ferguson and Thompson [15] and Tepfers [16] bond strength was found to increase with concrete strength approximately in proportion to the square root of the cube strength of concrete.

The coating factor ($\beta_i$) for bond strength was determined from the ratio of the corrected test bond strength of coated bars to the corrected test bond strength of uncoated bars for epoxy and vinyl chloride coated bars.

\[
\beta_i = \frac{\tau_i(\text{coated})}{\tau_i(\text{uncoated})} \sqrt{\frac{35}{f_{cu}}} \tag{11}
\]
The coating factor $\beta_1$ for epoxy was determined with an average of three beams for each bar diameter and was found to be 0.84, 0.95 for 16 mm, 20 mm diameter bars respectively. Similarly, the average bond reduction factors for vinyl chloride coated bars for three beams reinforced with 16 mm, 20 mm bars respectively were found to be 0.89 and 0.95 see Table 4.

Table 4. Coating Factor, $\beta_1$.

| Diameter (mm) | Coating Factor | Epoxy | Vinyl Chloride |
|---------------|----------------|-------|----------------|
|               | $\beta_1$ = $\frac{\tau_t(coated)}{\sqrt{\tau_{tc}}} \frac{1}{\sqrt{35}} f_{cu}$ |       |                |
| 16            | 0.70           | 0.81  | 0.84           |
|               | 1.02           |       |                |
| 20            | 0.96           | 1.10  | 0.95           |
|               | 0.78           |       |                |
| 16            | 0.72           | 0.96  | 0.89           |
|               | 0.99           |       |                |
| 20            | 0.92           | 0.96  | 0.95           |
|               | 0.98           |       |                |

The coating factor for 20 mm diameter bars are the same for epoxy and vinyl chloride but for 16 mm the coating factor is higher for vinyl chloride. Average result of three full size reinforced concrete beams appears reasonable in drawing a conclusion. Statistically, testing for significant difference between the mean value of epoxy and vinyl chloride using $t$ test $|t|$ was found to be 0.55, $t_{\alpha}$ table gave 2.92. Since the calculated value of $t$ (0.55) is less than the tabulated value of $t$ (2.92) at 5% level of significance, it implies that there is no significant difference between the mean values of epoxy and vinyl chloride. It should be noted, however, that full size reinforced concrete beams were tested and not models.

8. Conclusions
Based on the test results and analysis of test data it can be concluded that:
1. The bond efficiency of uncoated bars is generally higher than that of coated bars.
2. Bond strength and efficiency of bars coated with vinyl chloride are higher than that of epoxy and all other coating materials tested.
3. The coating factor for epoxy was 0.84, 0.95 for 16 mm, 20 mm diameter bars respectively. While vinyl chloride had a coating factor of 0.89 and 0.95 for 16 mm and 20 mm diameter bars.
4. Statistically, there appear to be no significant difference between the bond efficiency of the two materials (epoxy and vinyl chloride).

Acknowledgements
Late Emeritus Prof. C. O. Orangun’s interest, criticism and useful suggestions are gratefully acknowledged.

Julius Berger Nig. Plc provided the materials, labour used in the construction of the formworks, reinforcement cages, casting, curing and transportation to the Concrete Laboratory, University of Lagos. The assistance is thankfully acknowledged. Berger Paints Nig. Ltd. supplied the Epoxy coating used for the investigation. Vinyl Chloride and other coatings were supplied by International Paints for West Africa (IPWA). The assistance is appreciated and acknowledged. Sand blasting and coating of the steel rods were carried out free of charge by Messrs John Alapo Nig. Ltd. The assistance is thankfully acknowledged. The technical staff
of the Concrete Laboratory, University of Lagos assisted in testing the beams, cubes and reinforcements, the assistance is acknowledged.

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Appendix A
Notations

$A_s$  Area of tension reinforcement
$\alpha_v$  shear span
b  width of beam
BS  British standard
c  minimum cover
$c_b$  thickness of bottom concrete cover
$c_s$  thickness of side concrete cover
d  effective depth of beam
d_b  diameter of bar
$f_{bud}$  ultimate anchorage bond stress
$f_c$  cylinder strength of concrete
$f_{cu}$  characteristics cube strength
$f_s$  stress in steel
$f_y$  characteristics strength of reinforcement
$k_1$  ratio of the average compressive stress to the characteristic cube strength $f_{cu}$
k_2  ratio of the depth of the centroid of the stress block to the neutral axis depth
l_s  lap length
$M_u$  ultimate test bending moment
Q  applied load
$\tau_{aci}$  Ultimate bond stress recommended in ACI 318 - 02
$\tau_{BS8110}$  ultimate bond stress recommended in BS 8110:1997
$\tau_{cal}$  theoretical bond stress
$\tau_t$  test bond stress
x  depth of neutral axis
$\rho$  steel ratio $A_s/\pi d_b$
$\phi_e$  effective bar size
$\varepsilon_c$  strain in concrete in compression
$\varepsilon_s$  strain in tension reinforcement
$\beta$  Bond coefficient
E  epoxy coated bars
CR  chlorinated rubber coated bars
VC  vinyl chloride coated bars
ZS  zinc ethyl silicate coated bars
U  uncoated beam (reference)
T  tyrolin coated bars