ЕФЕКТ ОТ ПРИЛАГАНЕ НА СМЕС ОТ МАТЕРИАЛИ ЗА ПОКРИТАНЕ НА АРМИРОВКАТА ВЪРХУ ЕФЕКТИВНОСТТА НА НЕЙНОТО СЦЕПЛЕНИЕ

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EFFECT OF COATING MATERIALS MIXTURE ON BOND EFFICIENCY OF EPOXY COATED LAPPED SPLICES

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Abstract:
This paper gives a report of research investigation carried out in an attempt to improve the bond resistance of epoxy coated bars. Eighteen full size beams of varying lengths and sectional dimensions with lap spliced bars in constant moment region were cast and tested in a third point loading system. Two varying bar diameters (T16mm and T20mm) were coated independently with epoxy and with a mixture of epoxy and tyrolin, and a mixture of epoxy, cement and sand. The ultimate moment from the tests were used to determine the stress developed in the steel rods. The bond efficiency, τt / τcal, of the coating materials applied independently, and as mixtures was compared. Application of mixture of epoxy and tyrolin, gave an improved bond efficiency than epoxy alone and a mixture of epoxy, cement and sand by 17.58 %, 0.92 % respectively for 16 mm diameter bars. While the application of mixture of epoxy, cement and sand gave a higher bond efficiency than epoxy alone and a mixture of epoxy and tyrolin by 4.62 % and 3.66 % respectively for 20 mm diameter high yield bars.

Keywords:
Bond Resistance Lapped Splice, Independent, Mixture, Epoxy, Tyrolin.

1. INTRODUCTION

Corrosion is known to cause early deterioration of reinforcing bars. High humidity, especially in the southern part of Nigeria also results in early corrosion and deterioration of reinforced concrete structures. Water, in molecular or gaseous form, penetrates the concrete and attack the reinforcement corroding, expanding and scaling of the steel rods. This phenomenon leads to cracking and spalling of the concrete cover, reduction in diameter of reinforcement and subsequent reduction in the strength of structural elements, thus necessitating in many cases extensive repairs of structural elements. Coating of reinforcing bars is an accepted way of

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preventing corrosion of reinforcing bars. Of all the coating materials analyzed and investigated so far, only epoxy showed a good promise, Clifton and Mathey [1].

Epoxy coating has its own shortcomings, besides being expensive, the bond between concrete and epoxy coated steel rods is reduced Treece and Jirsa [2], Choi et al. [3], Osifala [4]. There is therefore an urgent need to find ways of improving the bond resistance of coated bars. In the quest to increase the bond performance of coated bars, it may not be out of place to investigate bars coated with a mixture of two or three materials: (tyrolin + epoxy); (epoxy + cement + sand). It is possible that one or all these combinations may give the much desired improvement in bond performance of coated bars.

The mode of application of organic coating materials, e.g. epoxy, polyvinyl chloride has been found not to significantly affect the bond strength of coated bars Mathey and Clifton [5]. There is no information yet on the effect of mode of application of non-organic coating materials such as tyrolin, and/or a mixture of organic and non-organic materials. Attempt to obtain this information should prove worthwhile. Hence the aim of this investigation is to generate data on bond between concrete and coated steel as well as find a way by which the bond resistance of coated bars could be improved.

1.1. Research significance

The research investigation was carried out with full size beams; which is rare due to cost. Full sized beam tests gave more realistic results as expected in practice, thus providing solutions to practical problems on bond in reinforced concrete.

A new way of improving bond resistance and efficiency of coated reinforcing steel is identified: *Coating with a mixture of epoxy and tyrolin gave a higher bond resistance than bars coated with epoxy alone*.

2. TEST PROGRAMME

The test programme was in two phases, preliminary and confirmatory. One beam was cast with each bar diameter in the preliminary investigation, while two beams were cast for each bar diameter in the confirmatory tests.

2.1. Design of test beams

Eighteen full size beams were cast; six beams were cast for the preliminary investigation and twelve beams for the confirmatory tests. The beams were of three sizes, 300 mm x 200 mm and 300 mm x 18 0mm. The main bars were 20 mm and 16 diameter high yield bars. The lengths varied with the bar diameters as 2.90 m and 2.75 m respectively. The design of the beams is shown in Fig. 1 and the beam data are shown in Table 1. 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 prevent shear failure.

The ultimate anchorage bond length recommended in BS 8110:1985 was used in this investigation.

$$l_s = \frac{0.87 f_y \phi}{4\beta\sqrt{f_{cu}}} . \qquad (1)$$

Lapped bars in contact, and lapped bars spaced apart have been reported to give satisfactory bond performance by Ferguson and Breen [6]. The contact arrangement was adopted 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 l_s + 300 mm.

The length of beams varied with the lap lengths and the shear spans. Failure mode in flexure is strongly dependent on the shear-span / effective depth ratio (a_v/d). Based on reported experimental studies in Kong and Evans [7] the failure pattern to ensure flexural failure was used. a_v/d was taken as 3, hence $a_v = 3d$.

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. The depth of all beams was 300 mm while the length is a function of lap length and shear span thus length $L = l_s + 300\text{ mm} + 2a_v + 200\text{ mm}$.

Table 1. Beam Data

Beam Name	b (mm)	Tensile Reinft.	A_s (mm^2)	Lap Lgth.+ 300 mm	Shear Span a_v (mm)	Beam Length (m)
A-ECB-1A	180	2T16	402	940	801	2.75
A-ECB-1B	180	2T16	402	940	801	2.75
A-ECB-1C	180	2T16	402	940	801	2.75
A-ECB-2A	200	2T20	628	1100	795	2.90
A-ECB-2B	200	2T20	628	1100	795	2.90
A-ECB-2C	200	2T20	628	1100	795	2.90
C-METCB-13A	180	2T16	402	940	801	2.75
C-METCB-13B	180	2T16	402	940	801	2.75
C-METCB-13C	180	2T16	402	940	801	2.75
C-METCB-14A	200	2T20	628	1100	795	2.90
C-METCB-14B	200	2T20	628	1100	795	2.90
C-METCB-14C	200	2T20	628	1100	795	2.90
C-MECSCB-16A	180	2T16	402	940	801	2.75
C-MECSCB-16B	180	2T16	402	940	801	2.75
C-MECSCB-16C	180	2T16	402	940	801	2.75
C-MECSCB-17A	200	2T20	628	1100	795	2.90
C-MECSCB-17B	200	2T20	628	1100	795	2.90
C-MECSCB-17C	200	2T20	628	1100	795	2.90

h = 300 mm;
c_b = c_3 = 25 mm;
WS = All beams are without stirrup over lap;
ECB – Epoxy Coated Bars;
METCB – Mixture Epoxy Tyrolin Coated Bars;
MECSCB – Mixture Epoxy Cement Sand Coated Bars.

2.2. Preparation and application of coating materials

After cutting to size the reinforcements were sand blasted to remove the rusts. The mode of application of organic coating materials e.g. Epoxy, Polyvinyl Chloride has been found not to significantly affect the bond strength of coated bars, Mathey and Clifton [5]. Coating could be applied by brushing, spraying, dipping (impregnation) and by fusion. Coating materials were sprayed round the steel rods in this investigation.

2.3. Epoxy Zinc Rich

Epoxy Zinc Rich used for this test is in two parts, Part A, the base and Part B, 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 in a container. Thinner was added until the mixture was light enough to pass through the nozzle of a conventional spraying gun. The mixture was then sprayed, in one coat, on the portions marked out on the reinforcements and allowed to dry in the shade with no direct exposure to sunshine.

2.4. 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 totalling 3.627 kg of sharp sand and 3.627 kg of cement were thoroughly mixed to achieve a uniform consistency; 2.00k g of water was added and further uniformly mixed. 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 three days before the reinforcement cages were made.

2.5. Preparation and application of mixed coating materials (Tyrolin + Epoxy)

Epoxy resin in its two parts (A and B), the components were mixed in ratio 3:1 (i.e. 750 ml of epoxy part A was mixed with 250 ml of Part B). 450 ml of thinner was added and thoroughly mixed as recommended by the manufacturer. The two materials (tyrolin and epoxy) were poured into a container and mixed thoroughly. Tyrolin spraying machine was used to apply the mixture on the reinforcing bars.

In the confirmatory tests, the constituents of tyrolin were measured by weight and thoroughly mixed as described earlier. Epoxy in ratio 3:1 (Part A and Part B) was weighed, Part A 750 ml, Part B 250 ml and 450 ml of Thinner were thoroughly mixed in another container until a uniform mix was achieved. The two materials (Tyrolin and Epoxy) were poured into a container and thoroughly mixed. The mix ratio of tyrolin + epoxy was 4:1. Tyrolin spraying machine was used to apply the mixture on the reinforcing bars.

2.6. Preparation and application of mixture of Epoxy, Cement and Sand

Dry sand and cement in the same measurements for tyrolin above were thoroughly mixed without water. Epoxy parts were also mixed in ratios 3:1. 1800 ml of epoxy part A was mixed with 600 ml of epoxy part B. 2.40 litres of thinner was mixed with the measured epoxy parts A and B. The two mixtures were added together i.e. cement - sand and Epoxy parts A and B and the thinner. The mixture was stirred thoroughly until a uniform colour was achieved. Tyrolin spraying machine was used to spray the mixture on the reinforcing rods.

In the confirmatory tests, 2.902 kg of Grade 14 sand, 0.725 kg of Grade 25 sand totaling 3.627 kg of sharp sand and 3.627 kg of Cement were thoroughly mixed to achieve a uniform consistency. Epoxy parts A and B in ratio 3:1 i.e. 1050 ml Part A with 350ml Part B and 1000 ml of thinner were first thoroughly mixed. Mixture of cement and sand were mixed with epoxy till a uniform consistency was achieved. The mix ratio of Sand : Cement : Epoxy was 1:1:1.01 by weight. Tyrolin spraying machine was used to spray the mixture on the rods and allowed to dry for seven days in the shade.

3. MANUFACTURE OF CUBES AND BEAMS

The concrete used for the investigation was concrete class U5000 ready mix with targeted cube strength of 35 N/mm^2. The strengths achieved at test are in Table 2.

The wooden beam moulds were oiled. The reinforcement cages were put in the mould and concrete spacers were placed at intervals at various locations bottoms and sides. The ready mixed concrete was poured from a rotating mixer, and vibrated with poker vibrator. The concrete beams were covered with nylon to prevent a rapid evaporation of the mixing water, and were demoulded after 24 hours. The beams were then placed on wooden joists in the storage area, and cured by wetting at intervals for over seven (7) days.

Table 2. Beam and strength achieved

Beam Name	Cube Strength, f_{cu} (N/mm^2)
A-ECB-1A A-ECB-2A	31.09
B2-METCB-14A B2-METCB-13A	27.53
B2-MECSCB-16	30.67
A-ECB-2B A-ECB-1C	37.90
A-ECB-2C A-ECB-1B	36.98
C-METCB-14B C-METCB-14C	32.30
C-METCB-13B C-METCB-13C	31.68
C-MECSCB-16B C-MECSCB-16C	33.65

Table 3. Characteristics of Hognestad Et-Al's Stress Block

S/N	f_{cu} (N/mm^2)	k_1	k_2	ε_{cu}
1.	31.09	0.611	0.457	0.0034
2.	27.53	0.632	0.461	0.0035
3.	30.67	0.613	0.458	0.0034
4.	37.90	0.575	0.450	0.0033
5.	36.98	0.578	0.449	0.0033
6.	30.19	0.616	0.460	0.0035
7.	32.30	0.605	0.455	0.0034
8.	31.68	0.610	0.456	0.0034
9.	33.65	0.596	0.451	0.0034

4. ANALYSIS AND DISCUSSION OF TEST RESULTS

Experimental investigation reported in Ferguson and Thompson [9], Orr [10] have shown that it is not essential to take strain measurement to establish steel stress. The steel stress developed in each beam was therefore 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 is in the constant moment region. The ultimate moment at the point load is

$$M_u = \frac{Q}{2}(a_v). \tag{2}$$

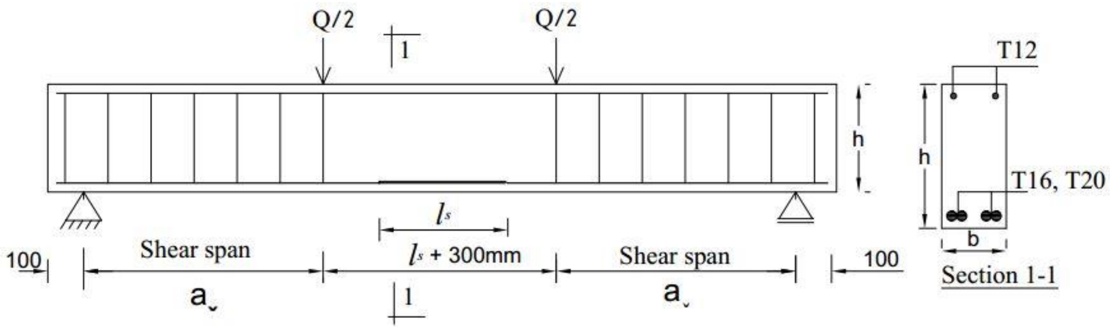

Figure 1. Typical beam without stirrup over lap.

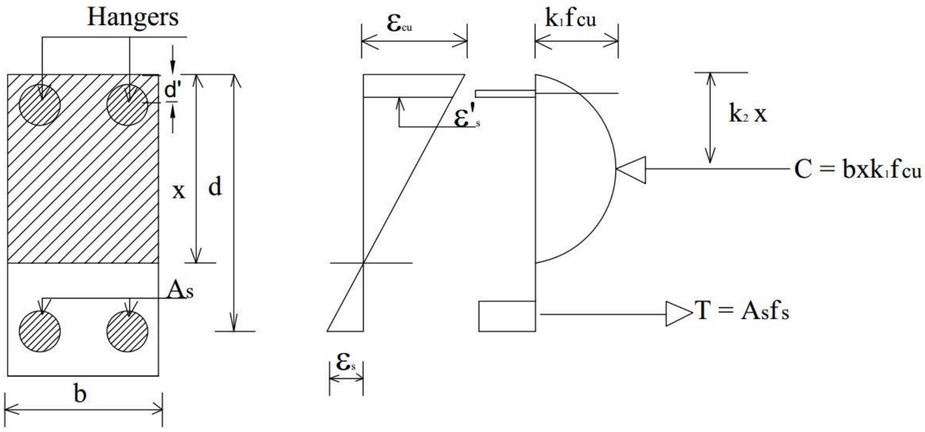

Figure 2. Strain and stress distribution at failure.

From the equilibrium condition, Figure 2.

$$k_1 f_{cu} bx = A_s f_s \,. \tag{3}$$

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

$$M_u = A_s f_s (d - k_2 x) \tag{4}$$

from where

$$\frac{M_u}{bd^2} = lf_s - \frac{k_2}{k_1}\frac{(lf_s)^2}{f_{cu}} \,. \tag{5}$$

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 in Kong and Evans [7] and universally accepted was used. Depending on the cube strength, various values of k_1 and k_2 and ε_{cu} are tabulated in Table 4. 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.

4.1. Test bond stress, τ_t

The bond strength is the average stress along the length of the splice. It was calculated as the force developed in the bar divided by the product of the splice length and the nominal perimeter of the bar. From equilibrium

$$\begin{aligned} A_s f_s &= \tau_t \pi \phi_e l_s \\ \tau_t &= \frac{f_s \pi \phi_e^2}{4 l_s \pi Ø_e} \\ \tau_t &= \frac{f_s \phi_e}{4 l_s} \end{aligned} \tag{6}$$

The steel stress developed in each beam obtained from equation (5) was substituted in (6) to obtain the τ_t.

Table 4. Beam Test Results

Beam Name	f_{cu} N/mm²	M_u kN.m	f_s N/mm²	τ_t N/mm²	τ_{cal} N/mm²	τ_{BS} N/mm²	$\frac{\tau_t}{\tau_{cal}}$	$\frac{\tau_t}{\tau_{BS}}$	$\frac{\tau_t}{\tau_{cal}}$	$\frac{\tau_t}{\tau_{BS}}$
A-ECB-1A	31.09	62.64	370.98	2.32	3.14	2.79	0.74	0.93	0.91	1.03
A-ECB-1B	36.98	72.25	471.98	2.94	3.42	3.04	0.86	0.97		
A-ECB-1C	37.90	85.07	589.58	3.86	3.46	3.08	1.12	1.25		
A-ECB-2A	31.09	88.40	430.13	2.69	2.72	2.79	0.99	0.96	1.08	1.05
A-ECB-2B	37.90	113.45	539.32	3.89	3.37	3.08	1.12	1.13		
A-ECB-2C	36.98	92.38	452.16	2.83	2.96	3.04	0.95	0.93		
C-METCB-13A	27.53	44.86	466.05	2.91	2.95	2.62	0.99	1.11	1.07	1.21
C-METCB-13B	31.68	55.27	581.72	3.64	3.17	2.81	1.15	1.29		
C-METCB-13C	31.68	52.47	548.10	3.43	3.17	2.81	1.08	1.22		
C-METCB-14A	27.53	62.01	430.91	2.69	2.56	2.62	1.05	1.03	1.09	1.07
C-METCB-14B	32.30	72.35	505.10	3.16	2.77	2.84	1.14	1.11		
C-METCB-14C	32.30	69.96	485.38	3.03	2.77	2.84	1.09	1.07		
C-MECSCB-16A	27.53	37.65	383.31	2.40	2.95	2.62	0.81	0.91	0.98	1.11
C-MECSCB-16B	31.68	52.87	552.87	3.46	3.17	2.81	1.09	1.23		
C-MECSCB-16C	33.65	52.87	549.29	3.43	3.26	2.90	1.05	1.18		
C-MECSCB-17A	30.67	66.78	463.21	2.90	2.70	2.77	1.07	1.05	1.13	1.10
C-MECSCB-17B	33.65	73.54	511.63	3.20	2.83	2.90	1.13	1.10		
C-MECSCB-17C	33.65	75.92	531.48	3.32	2.83	2.90	1.17	1.15		

4.2. Theoretical bond stress, τ_{cal}

The theoretical bond stress, τ_{cal}, was determined from a semi-empirical statistical regression equation developed by Orangun *et al.* [11]. For bars with no transverse reinforcement

$$\tau_{cal} = \left[1.2 + 3\left(\frac{c}{d_b}\right) + 50\left(\frac{d_b}{l_s}\right)\right] f_c^{0.5}. \quad (7)$$

Equations 7 is in imperial unit and concrete cylinder strength. The expression was converted to SI units and modified for use with concrete cube strength by Cairns and Abdullah [12] to give:

$$\tau_{cal} = \left[0.09 + 0.24\frac{c}{d_b} + 3.9\frac{d_b}{l_s}\right]\sqrt{f_{cu}}. \quad (8)$$

The bond strength equation in (8) proposed by Orangun et al. [11] have been widely discussed, Benedict, Vanashie, Chin et al. [13] accepted and used as reference by various researchers since it was published. Thus the bond strength equation proposed by Orangun et al. [11] was adopted as the formula for theoretical bond stress. Orangun et al. [11] adopted theoretical bond stress equation formed the basis of the bond strength equation in the 1995 and 2002 American Concrete Institute (ACI) codes. Leet, Kenneth [14].

4.3. Bond stress using BS 8110's recommendation, $\tau_{BS\,8110}$

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

$$\tau_{\mathrm{BS\ 8110}} = \beta\sqrt{f_{cu}}. \quad (9)$$

with the factor β, taken as 0.5 because deformed bars were used in tension. (BS 8110: Clause 3.12.8.4)

5. DISCUSSION OF TEST RESULTS

Effect of Application of a Mixture of Coating Materials on Bond Resistance

Preliminary tests were run in an attempt to improve the bond performance of epoxy coated bars by the application of a mixture of two or more materials. Beams were cast with two coated bars of 16 mm and 20 mm diameter. The beam data and the test results are shown in Tables 1, 4 and Fig. 3.

In order to reduce the cost and time of application of coating materials and its improvement agent (tyrolin) attempt was made at mixing the materials before using the mixture to coat. The beam data and the test results of the mixture of epoxy and tyrolin and a mixture of epoxy + cement + sand are in tables and figure listed above.

Mixture of epoxy and tyrolin gave higher bond efficiency, in the bar diameters tested than in those of epoxy alone and a mixture of epoxy + cement + sand for 16 mm diameter bars. The water necessary for the chemical reaction of cement to take place, which is missing in the mixture of epoxy, cement and sand, may have contributed to the weak bond resistance observed with this coating.

Mixture of epoxy + cement + sand gave the highest bond resistance when compared with mixture of epoxy and tyrolin and epoxy alone for 20 mm diameter bars. Ordinarily, bond efficiency of 20 mm diameter bars is expected to be lower than that of 16mm diameter bars, the effect of coating which is thick may have caused the improved performance recorded for 20 mm diameter bars. Moreover, the surface area is larger; the groove created by the mixture is more. This may have caused the improvement recorded in specimen with 20 mm diameter bars.

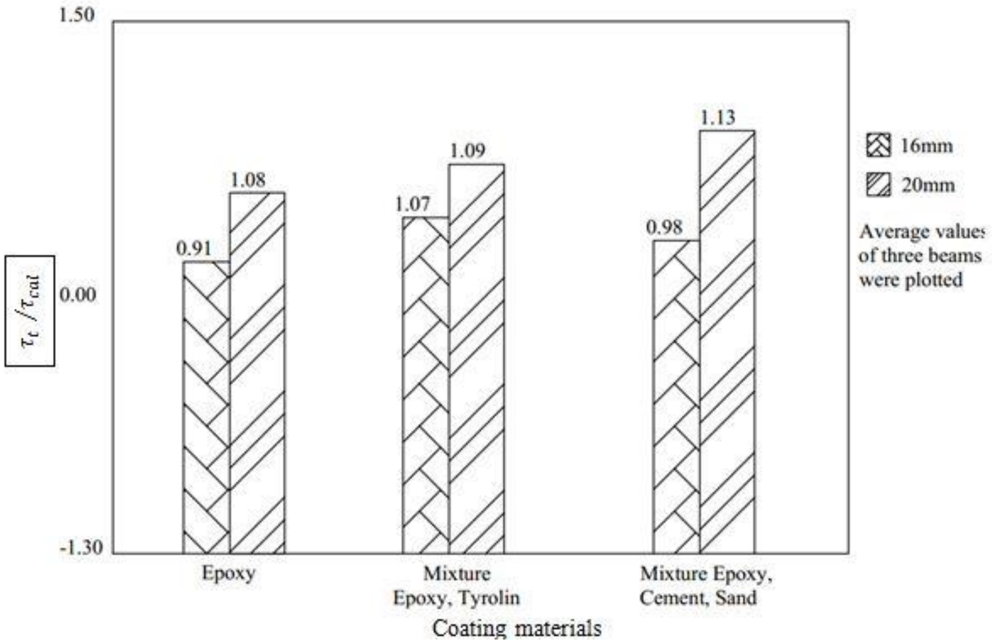

Figure 3. Coating materials applied as a mixture.

6. CONCLUSION

Based on the test results and analysis of the test data the following conclusions are drawn:

i. Bond efficiency of bars coated with a mixture of epoxy and tyrolin is higher than bars coated with epoxy alone and a mixture of epoxy, cement and sand by 17.58 and 0.92 percent for 16 mm diameter bars respectively.
ii. Bond efficiency of bars coated with a mixture of epoxy, cement and sand is higher than bars coated with epoxy alone and mixture of epoxy and tyrolin by 4.62 and 3.66 percent for 20 mm diameter bars respectively.
iii. Both mixtures improved the bond resistance and efficiency of epoxy coated bars.

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NOTATIONS

A_s area of tension reinforcement;
A_s^l area of compression reinforcement;
a_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_s^l cylinder strength of concrete;
f_{cu} characteristics cube strength;
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;
L length of beam;
M_u ultimate test bending moment;
Q applied load;
$\tau_{BS\ 8211}$ ultimate bond stress recommended in BS 8110: 1997
τ_{cal} theoretical bond stress;
τ_t test bond stress;
x depth of neutral axis;
WS without stirrup over lap;
ℓ steel ratio, (A_s/bd);
ϕ_e effective bar size;
ε_{cu} strain in concrete in compression;
ε_s strain in tension reinforcement;
β bond coefficient;

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