Corrosion Effect on Flexural Mechanical Property of Concrete Reinforcement Steel in Corrosive Environment

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ABSTRACT

The corrosion of steel bars in concrete is affected by wide range of parameters such as water-to-cement ratio, permeability, concrete cover, crack width and the use of supplementary cementitious materials. The research work evaluated the flexural behavior of reinforcing (reinforcement) steel of non-coated and coated specimens with acacia senegal exudates/resins of varying coated thickness embedded in concrete beam, immersed in corrosive media and accelerated for 150 days. Obtained results after accelerated duration confirmed non-coated specimen with corrosion potential attributes of cracks and spalling. Averaged derived flexural failure load values of corroded samples percentile difference of -32.0242% against 27.96875% and 46.7759 against non-corroded and acacia senegal exudates coated specimens. Midspan deflection averaged value percentile difference of 77.89474% against -43.787% and -44.8743% controlled and coated specimens. Average yield strength, 460MPa, summed up to 100% with 0.00% of percentile value and difference. Averaged ultimate tensile strength, percentile difference of -10.2433% against 11.41226% and 11.41226 of non-corroded and coated specimens. Averaged strain ratios percentile difference values of -10.9478% against 12.29364% and 12.82435% of non-corroded and coated specimens. Averaged elongations percentile difference values of -41.8705% against 72.02975% and 70.21979% for non-corroded and coated specimens. Summarized results of corroded showed and exhibited high flexural failure loads against non-corroded and coated specimens, midspan deflection rates are higher to non-corroded and coated specimens, ultimate tensile strength of corroded specimens are all higher to non-corrode and coated specimens. Overall experimental tests showed that mechanical properties of reinforcing steel are adversely affected by the presence corrosion.

Key Words: Corrosion, Corrosion inhibitors, Pull-out Bond Strength, Concrete and Steel Reinforcement

INTRODUCTION

Corrosion of reinforcing steel in concrete structure assumes many forms and their product results occur when there is chemical reaction between metal and its environment. Rust products form on the bar, expanding its volume and creating stress in the surrounding concrete causing cracking, spalling and staining of concrete, and reduce the effective cross-sectional area of reinforcing bars, thereby having less load carrying capacity. The corrosion of steel bars in concrete is affected by a wide range of parameters such as water-to-cement ratio, permeability, concrete cover, crack width and the use of supplementary cementitious materials.

[1] Stated that bonding is more likely to affect structural capacity than is loss of tensile strength of reinforcement resulting from general corrosion. Experiment results indicated that the level of reinforcement corrosion does not influence the tensile strength of steel bars (calculated on the actual area of cross-section), but reinforcing steel bars with more than 12% corrosion indicates a brittle failure.

[2] Concluded that the strength ratio and elastic modulus of reinforcement are not significantly affected by corrosion and consequently the strength and modulus of elasticity of non-corroded bars can be adopted in practice.

[3] Investigated the residual yield strength structural capacity effect of non-corroded, corroded and inhibited steel bar. The results of coated steel bar with three different resins / exudates extracts of *Symphonia globulifera* linn, *ficus glumosa* and *acardium occidentale* l.) versus corroded on comparison, the flexural strength failure load are 29.50%, 28.505, 29.57% against 22.30% corroded, midspan deflection are 31.14%, 25.30%, 22.30% against 39.30% corroded, tensile strength 11.84%, 12.13%, 12.14% against 10.17% and elongation are 32.40%, 32.13%, 32.40% against 46.30% corroded. Overall results indicated that coated steel bar showed higher values increased in failure load and tensile strength while corroded decreased in elongation and midspan deflection.

[4] Investigated the flexural action of combined effect of corrosion and sustained loads of reinforced concrete corroded beams. Test results showed that the presence of a sustained load and associated flexural cracks during corrosion exposure significantly reduced the time to corrosion cracking and slightly increased the corrosion crack width. They found that crack width would propagate 22% faster in loaded conditions, observed that with 8.9% and 22.2% mass loss, strength losses of 6.4% and 20.0% respectively

[5] Investigated the effect on flexural residual yield strength capacity of three different resins/exudates extract of trees of *dacryodes edulis*, *moringa oleifera* lam, *mangifera indica* paste coated reinforcement on the concrete beam. Flexural strength failure loads of coated members with *dacryodes edulis*, *moringa oleifera* lam, *mangifera indica* are 35.78%, 27.09%, 29.42% against 22.30% decreased in corroded, midspan deflection are 18.57%, 28.30%, 27.43% against 39.30% increased in corroded, elongation are 28.75%, 31.50%, 31.60 against 46.30% increased in corroded and tensile strength are 14.18%, 12.29%, 12.08% as against 10.17% decreased in corroded respectively. Entire results showed that low load subjection is recorded in coated members at failure loads as against in corroded with high deflection and elongation.

[6] Investigated the flexural capacity loss with steel cross-sectional loss due generalized corrosion of embedded steel using specimens of concrete beams with 100 mm × 150 mm cross section and 1500 mm in length cast with chlorides. The specimens were tested in flexure under three point loading. They concluded that flexural load capacity decreased by 60% with only 10% ratio, the most important parameter affecting flexural load capacity reduction, because pitting corrosion greatly decrease the cross sectional area of the steel at a certain location and change the steel from ductile behavior to brittle behavior.

[7] Examined the effect/impact of corrosion inhibitors on flexural strength of failure load, midspan deflection, tensile strength and elongation of steel reinforcement layered with resins/exudates of *mangifera indica* extracts as corrosion inhibitors. More results recorded on experimental work showed flexural strength failure load, midspan deflection, tensile strength

and elongation as 29.09%, 31.20%, 11.75% and 31.50% for non-corroded, 29.42%, 27.43%, 12.09% and 31.60% for coated concrete beam respectively. Entire results showed the effect of corrosion on the flexural strength of reinforcement that led to low load on failure load and higher midspan deflection on corroded beams and flexural load on failure load and low midspan deflection on non-corroded and coated concrete beam members resulting to attack on surface condition of reinforcement from corrosion.

[8] Investigative study was carried out to ascertain the utilization of natural inorganic extracts of tree resin/exudates to assess the yield strength capacity of reinforced concrete beam members under corrosion accelerated medium. resins/exudates pasted of thickness ranges of 150µm, 250µm and 350µm were directly coated on steel bar, embedded into concrete and performed corrosion acceleration process performed on both uncoated and coated reinforced concrete members. Non – corroded and coated members in comparison with corroded recorded increasing values on flexural strength failure load by 23.8% and 29.59% against 22.30% of corroded, tensile strength non – corroded and coated increased by 12.03% , 12.14% over 10.17 % of corroded while decreasing values on midspan deflection of 28.30% and 22.30%, elongation 31.5% and 32.46% recorded on non-corroded and coated concrete beam members as against 39.30% and 46.30% of corroded respectively.

[9] Investigated the effects of corrosion on the residual structural steel bar capacity of resins/exudates inhibited and non-inhibited reinforced concrete beam members. Steel reinforcements were coated with moringa oleifera lam resins/exudates from trees extract (Inorganic inhibitors), embedded into concrete beam members and exposed to sodium chloride medium representing laboratory harsh saline marine environment. Further recorded results on non-corroded flexural strength test of failure load 29.09%, midspan deflection 28.30%, tensile strength 12.03% and elongation 31.50%, for coated beam members, failure load 29.42%, midspan deflection 27.42%, tensile strength 12.09% and elongation 31.80%, for corroded beam members, failure load decreased by 22.50%, midspan deflection increased by 39.30%, tensile strength decreased to 10.17% and elongation by increased 46.30%.

[10] investigated the effect of corrosion on the flexural strength and mid-span deflection of steel reinforcements coated with resins / exudates of trees extract known as inorganic inhibitors (dactyodes edulis-African Pear). Corrosion accelerated test were conducted on uncoated and dactyodes edulis resin pastes coated thicknesses of 150µm, 250µm and 300µm on steel reinforcement before corrosion test for 60 days to simulated corrosion process. Results obtained indicated that the flexural failure strength, and elongation increased by (29%) and (48%) respectively for the dactyodes edulis coated steel members, the mid-span deflection decreased by 26%, elongation increased by 23% and 32% respectively, while the mid-span deflection decreased by 40%.The resin (dactyodes edulis) added strength to the reinforcement.

[11] experimented on the effects of corrosion and inhibitors (Inorganic origin) extracts known as resins/exudates from trees barks on the residual flexural strength of concrete beam members immersed in corrosion accelerated medium for 90 days to ascertain possible changes on surface conditions of investigated samples. Further results obtained of corroded concrete beam members were 22.50%, 39.30%, 10.19% and 46.30 of failure load, midspan deflection, ultimate tensile strength and elongation, for non- 29.09%, 28.30%, 12.03% and 31.50%, for coated beam members , 28.5%, 25.30%, 12.13% and 32.12% respectively. This showed lower load and higher deflection in corroded members and higher in non-corroded and coated, higher elongation in corroded and lower in non-corroded and coated.

MATERIALS AND METHODS FOR EXPERIMENT

Aggregates

The fine aggregate and coarse aggregate were purchased. Both met the requirements of [12].

Cement

Portland limestone cement grade 42.5 is the most and commonly type of cement in Nigerian Market. It was used for all concrete mixes in this investigation. The cement met the requirements of [13].

Water

The water samples were clean and free from impurities. The fresh water used was gotten from the tap at the Civil Engineering Department Laboratory, Kenule Beeson Polytechnic, Bori, and Rivers State. The water met the requirements of [14].

Structural Steel Reinforcement

The reinforcements are gotten directly from the market in Port Harcourt and met the requirements [15]

Corrosion Inhibitors (Resins / Exudates) *Acacia senegal*

The study inhibitor (*Acacia senegal* exudates) of natural tree resins/exudates extracts.

Methods

Present study involves direct application of resins / exudates of trees extract known as inorganic inhibitor *acacia Senegal* exudates), layered/coated on reinforcement steel ribbed surface.

The samples of reinforced concrete beams of 150 mm x 150 mm x 750 mm, thickness, width and length specimens and ribbed bars of 16 mm embedded for corrosion test and flexural test for beam was investigated. This was aimed at achieving the real harsh and corrosive state, concrete specimens were ponded in solutions (NaCl) and the depth of the solution was maintained for the given period of experiment as to observe the significant changes that resulted from the actions of the accelerator (NaCl) and the specimens.

Specimen Preparation and Casting of Concrete Beams

Standard method of concrete mix ratio was adopted, batching by weighing materials manually. Concrete mix ratio of 1:2:4 by weight of concrete, water-cement ratio of 0.65. Manual mixing was used on a clean concrete banker, and mixture was monitored and water added gradually to obtain perfect mix design concrete. Standard uniform color and consistency concrete was obtained by additions of cement, water and aggregates. The test beams were cast in steel mould of 150mm x 150 mm x 750 mm. Fresh concrete mix for each batch was fully compacted by tamping rods, to remove trapped air, which can reduce the strength of the concrete and 16 mm reinforcements of coated and non-coated were spaced at 150 mm with concrete cover of 25 mm had been embedded inside the beam and projection of 100 mm for half-cell potential measurement. Specimens were molds are removed from specimen after 24hrs and cured for 28 days. The specimens were cured at room temperature in the curing tanks for accelerated corrosion test process and testing procedure allowed for 120 days first crack noticed and a further 30 days making a total of 150 days for further observations on corrosion acceleration process.

Flexure testing of Beam Specimens

Universal Testing Machine in accordance with BS EN 12390-2 was used for the flexural test and a total of 27 beam specimens were tested. After curing for 28 days, 6 controlled beams (non-corroded) was kept in a control state, preventing corrosion of reinforcement, while 18 beam samples of non-coated and exudates /resins coated were partially place in ponding tank for 150 days and examined accelerated corrosion process. An Instron Universal Testing Machine of 100KN capacity at a slow loading rate of 1 mm/min was used in the flexural test.

Beam samples were placed in the machine to specification, flexural test were conducted on a third point at two supports.

Tensile Strength of Reinforcing Bars

To ascertain the yield and tensile strength of tension bars, bar specimens of 16 mm diameter of non-corroded, corroded and coated were tested in tension in a Universal Testing Machine and subjected to direct tension until failure; the yield, maximum and failure loads being recorded. To ensure consistency, the remaining cut pieces from the standard length of corroded and non-corroded steel bars were subsequently used in the bond and flexural test.

RESULTS AND DISCUSSIONS

Results of 27 samples in table 1, 2 and 3 are derived into averaged values in 4 and summarized into summary of averages, percentile values and percentile values difference in 3.5 of flexural strength of concrete beam members as sampled, arbitrarily cast, cured for 28 days on normal and standard method, accelerated in corrosion medium environment for 120 days at first cracks observation and 30 days extended period and graphically represented in fig. 1 - 3.

Non-corroded Concrete Beam Members

Averaged derived flexural failure load values of non-corroded samples are 80.37kN, 80.25667kN, 80.72667kN, summed up to 80.45111kN with percentile difference of 27.96875% over -32.0242% corroded specimens. Midspan deflection average values are 6.603333mm, 6.846667mm, 6.306667mm, summed up to 6.585556mm with percentile difference of -43.787% over 77.89474% corroded specimens. Average yield strength, 460MPa, summed up to 100% with 0.00% of percentile value and difference, Average ultimate tensile strength, f_u , 632.6833MPa, 632.4167MPa, and 632.1167MPa, summed up to 632.4056MPa, percentile difference of 11.41226% over -10.2433% corroded specimens. Average strain ratios are 1.311667, 1.315, and 1.305, summed up to 1.305 with percentile difference values of 12.29364% over -10.9478%. Averaged elongations are 28.6055%, 28.6055%, 28.72883%, summed up to 28.55439% with percentile difference values of 72.02975% over -41.8705%. Summarized results of non-corroded over corroded specimens showed that non-corroded (controlled) samples superseded corroded samples properties in low flexural failure, low midspan – deflection, normal yield strength, high ultimate strength, low strain ratio.

Corroded Concrete Beam members

Averaged derived flexural failure load values of corroded samples are 63.543333kN, 62.490kN, 62.570kN, summed up to 67.97583kN with percentile difference of -32.0242% over 27.96875% and 46.7759 against non-corroded and acacia senegal exudates coated specimens. Midspan deflection average values are 13.133333mm, 12.833333mm, 12.78667mm, summed up to 12.91778mm with and percentile difference of 77.89474% against -43.787% and -44.8743% controlled and coated specimens. Average yield strength, 460MPa, summed up to 100% with 0.00% of percentile value and difference. Average ultimate tensile strength, f_u , 556.28333MPa, 554.75MPa, 554.8833MPa, summed up to 555.3056MPa, percentile difference of -10.2433% against 11.41226% and 11.41226 of non-corroded and coated specimens. Average strain ratios are 1.1583333, 1.165, and 1.148333, summed up to 1.157222 with percentile difference values of -10.9478% against 12.29364% and 12.82435% of non-corroded and coated specimens. Averaged elongations are 14.643333%, 14.423333%, 14.60333%, summed up to 14.55667% with percentile difference values of -41.8705% against 72.02975% and 70.21979% for non-corroded and coated specimens. Summarized results of corroded showed and exhibited high flexural failure loads

over non-corroded and coated specimens, midspan deflection rates are higher to non-corroded and coated specimens, ultimate tensile strength of corroded specimens are all higher to non-corroded and coated specimens. Overall experimental tests showed that mechanical properties of steel reinforcing steel are adversely affected by corrosion presence.

Acacia Senegal Resins/Exudates Steel Coated Concrete Beam Members.

Averaged derived flexural failure load values of coated samples are 80.320667kN, 80.427333kN, 80.39733kN, summed up to 80.38178kN with percentile difference of 46.7759 over -32.0242% over corroded specimens. Midspan deflection average values are 6.5966667mm, 6.6533333mm, 6.636667mm, summed up to 6.628889mm with and percentile difference of -44.8743% over 77.89474% corroded specimens. Average yield strength, 460MPa, summed up to 100% with 0.00% of percentile value and difference. Average ultimate tensile strength, f_u , 629.5167MPa, 629.550MPa, 629.4833MPa, summed up to 629.5167MPa, percentile difference of 11.41226% over -10.2433% corroded specimens. Average strain ratios are 1.325167, 1.3085, and 1.315167, summed up to 1.316278 with percentile difference values of -12.82435% over -10.9478% of corroded specimens. Averaged elongations are 26.4785%, 26.53517%, 26.47517%, summed up to 26.49628% with percentile difference values of 70.21979% over -41.8705% of corroded specimens. Summarized results coated specimens showed low flexural failure load, midspan deflection, strain ratio and ultimate tensile strength. The overall indications of tested specimens clearly showed that that coated exudates to reinforcing steels proved to be inhibitory to corrosion effects.

Table 1. Flexural Strength of Beam Specimens (Non-Corroded specimens)

s/no	Non-corroded Control Beam									
Beam	Samples	GAK	GBK	GCK	GDK	GEK	GFK	GGK	GHK	GIK
GBG1-1	Failure Load (KN)	80.43	80.43	80.25	80.22	80.22	80.33	81.03	80	81.15
GBG1-2	Midspan Deflection (mm)	6.35	6.43	7.03	7.14	6.23	7.17	6.26	6.43	6.23
GBG1-3	Bar diameter (mm)	16	16	16	16	16	16	16	16	16
GBG1-4	Yield Strength, f_y (MPa)	460	460	460	460	460	460	460	460	460
GBG1-5	Ultimate Tensile Strength, f_u (MPa)	631.85	633.75	632.45	631.25	633.75	632.25	632.05	632.85	631.45
GBG1-6	Strain Ratio	1.335	1.295	1.305	1.335	1.305	1.305	1.305	1.295	1.315
GBG1-7	Elongation (%)	28.5055	28.7055	28.6055	28.6755	28.1055	28.2055	28.7055	28.6755	28.8055

Table 2. Flexural Strength of Beam Specimen (Corroded specimens)

s/no		Corroded Beam								
Beam	Samples	GAK1	GBK1	GCK1	GDK1	GEK1	GFK1	GGK1	GHK1	GIK1
GBG2-1	Failure load (KN)	63.9	64.58	62.15	61.63	63.92	61.92	61.69	64.12	61.9
GBG2-2	Midspan Deflection (mm)	13.37	13.2	12.83	12.8	12.4	13.3	12.83	12.43	13.1
GBG2-3	Bar diameter (mm)	16	16	16	16	16	16	16	16	16
GBG2-4	Yield Strength, fy (MPa)	460	460	460	460	460	460	460	460	460
GBG2-5	Ultimate Tensile Strength, fu (MPa)	558.35	554.95	555.55	554.85	554.55	554.85	554.25	555.55	554.85
GBG2-6	Strain Ratio	1.165	1.155	1.155	1.195	1.145	1.155	1.155	1.145	1.145
GBG2-7	Elongation (%)	14.66	14.8	14.47	14	14.99	14.28	14.8	14.5	14.51

Table 3. Flexural Strength of Beam Specimens (Exudates/Resins Coated specimens)

		Acacia senegal Exudates (steel bar coated specimen)								
s/no		150µm (Exudate/Resin) coated			300µm (Exudate/Resin) coated			450µm (Exudate/Resin) coated		
Beam	Samples	GAK2	GBK2	GCK2	GDK1	GEK2	GFK2	GGK2	GHK2	GIK2
GBG3-1	Failure load (KN)	79.904	80.854	80.204	80.244	80.604	80.434	80.204	80.244	80.744
GBG3-2	Midspan Deflection (mm)	6.7	6.1	6.99	6.8	6.36	6.8	6.78	6.78	6.35
GBG3-3	Bar diameter (mm)	16	16	16	16	16	16	16	16	16
GBG3-4	Yield Strength, fy (MPa)	460	460	460	460	460	460	460	460	460
GBGE-5	Ultimate Tensile Strength, fu (MPa)	629.05	629.95	629.55	629.55	629.55	629.55	629.15	629.65	629.65
GBG3-6	Strain Ratio	1.3185	1.3385	1.3185	1.3085	1.3085	1.3085	1.2985	1.3185	1.3285
GBG3-7	Elongation (%)	26.2385	26.8585	26.3385	26.3085	26.7585	26.5385	26.4485	26.1585	26.8185

Table 4. Average Flexural Strength of Beam Specimens (Non-Corroded, Corroded Exudates/Resins Coated Specimens)

s/no	Samples	Non-Corroded Specimens Average Values			Corroded Specimens Average Values			Coated Specimens Average Values		
GBG4-1	Failure load (KN)	80.37	80.25667	80.72667	63.543333	62.49	62.57	80.320667	80.427333	80.39733
GBG4-2	Midspan Deflection (mm)	6.603333	6.846667	6.306667	13.133333	12.833333	12.78667	6.596667	6.6533333	6.636667
GBG4-3	Bar diameter (mm)	16	16	16	16	16	16	16	16	16
GBG4-4	Yield Strength, fy (MPa)	460	460	460	460	460	460	460	460	460
GBG4-5	Ultimate Tensile Strength, fu (MPa)	632.6833	632.4167	632.1167	556.28333	554.75	554.8833	629.5167	629.55	629.4833
GBG4-6	Strain Ratio	1.311667	1.315	1.305	1.1583333	1.165	1.148333	1.325167	1.3085	1.315167
GBG4-7	Elongation (%)	28.6055	28.32883	28.72883	14.643333	14.423333	14.60333	26.4785	26.53517	26.47517

Table 5. Summary of Percentile Flexural Strength of Beam Specimens (Non-Corroded, Corroded, Exudates/Resins Coated Specimens)

Beam	Samples	Summary of Averages			Percentile Values			Percentile Difference		
GBG5-1	Failure load (KN)	80.45111	62.86778	80.38178	127.9688	67.97583	146.7759	27.96875	-32.0242	46.7759
GBG5-2	Midspan Deflection (mm)	6.585556	12.91778	6.628889	56.21302	177.8947	55.12574	-43.787	77.89474	-44.8743
GBG5-3	Bar diameter (mm)	16	16	16	100	100	100	0	0	0
GBG5-4	Yield Strength, fy (MPa)	460	460	460	100	100	100	0	0	0
GBG5-5	Ultimate Tensile Strength, fu (MPa)	632.4056	555.3056	629.5167	111.4123	89.75673	111.7066	11.41226	-10.2433	11.70662
GBG5-6	Strain Ratio	1.310556	1.157222	1.316278	112.2936	89.05224	112.8244	12.29364	-10.9478	12.82435
GBG5-7	Elongation (%)	28.55439	14.55667	26.49628	172.0297	58.12948	170.2198	72.02975	-41.8705	70.21979

Fig. 1 Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

Fig. 2 Average Failure Load versus Midspan Deflection of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

Fig. 3 Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

Fig. 4 Average Ultimate Tensile Strength versus Yield Strength of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

Fig. 5 Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

Fig. 6 Average Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

Fig. 7 Ultimate Tensile Strength versus Elongation of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

Fig. 8 Average Ultimate Tensile Strength versus Elongation of Beam Specimens (Non-Corroded, Corroded and Resin Coated Specimens)

4.0 Conclusions

Experimental results gotten from tables 1 – 5 and fig. 1 – 3, below were used to draw conclusions for the study as follows:

- Summarized results of non-corroded over corroded specimens showed that non-corroded (controlled) samples superseded corroded samples properties in low flexural failure load, low midspan – deflection, normal yield strength, high ultimate strength and low strain ratio.
- Summarized results of corroded sample showed and exhibited high flexural failure loads over non-corroded and coated specimens, midspan deflection rates are higher to non-corroded and coated specimens, ultimate tensile strength of corroded specimens are all higher to non-corrode and coated specimens.
- Overall experimental tests showed that mechanical properties of steel reinforcing steel are adversely affected by corrosion presence.
- Summarized results indicated that coated specimens showed low flexural failure load, midspan deflection, strain ratio and ultimate tensile strength.
- The overall results indicated that tested specimens (coated exudates to reinforcing steels) proved to be inhibitory to corrosion effects.

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