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Effect of Resins / Exudates Inhibited Steel on the Flexural strength of Reinforced Concrete Beam under Corrosive Environment

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ABSTRACT

Experimental research work was performed and investigated on uncoated and corrosion inhibitors (Symphonia globulifera linn) resins / exudates paste coated steel reforcing bar. This was to determine the coating effects of corrosion on flexural load and midspan deflection on structural capacity of reinforced concrete beam members under harsh saline marine environment, represented in the laboratory with sodium chloride (NaCl) as corrosion accelerator. Corrosion test was performed on uncoated and coated concrete beam members with varying coating thickness of 150μm, 250μm and 350μm , embedded into concrete and cured for 90 days. Results obtained confirmed corrosion potential with the presence of stress within the steel and concrete surrounding, spalling and cracking. Further results obtained on comparison between uncoated (corroded) and coated are flexural failure load 22.50% to 29.50%, midspan deflection 39.30% to 31.14%, tensile strength 10.17% to 11.84% and elongation 46.30% to 32.40% respectively. Thus, results showed decreased in failure load and tensile strength of corroded members while increased in midspan deflection and elongation. This attributes was due to effect of corrosion and reduction in strength from degradation properties. Resins / exudates coated members showed higher failure load with low deflection.

Key Words: *Corrosion, Corrosion inhibitors, Flexural Strength, Concrete and Steel Reinforcement.*

1.0 INTRODUCTION

The end results of steel corrosion are manifested as a reduction in the bar diameter, wear and tear of the mechanical properties of the reinforcing steel as experienced by reinforced concrete structures built within the marine environment are due to chloride-induced corrosion of reinforcement which resulted from the presence of high chloride concentrations and humid or saturated conditions. Corrosion generates tensile stresses in steel reinforcement surroundings the in the concrete, resulting to early cracks. Cracks can reduce the overall strength and stiffness of the concrete structure and accelerate the ingress of aggressive ions, leading to other types of concrete deterioration and resulting in further cracking (Mehta & Gerwick, 1982). Principal factors such as concrete pH, chloride ions, oxygen and water needed to be considered in the controlled of corrosion inhibition of reinforcement. Methods adopted to control these factors are the use of epoxy coatings, inhibitors, buffers, electrochemical protection procedures and scavengers all known to be corrosion inhibitors.

Macdonald (2003) carried out the investigation of inhibitors in solutions of alkaline and extracts from cement. The extracts from cement experiment revealed corrosion was inhibited using sodium nitrite in the presence of chlorides while sodium benzoate did not. Furthermore, the initiation of corrosion was delayed with sodium nitrite, with the delay increasing with inhibitor content.
Novokshcheov (2000) studied and showed that calcium nitrite is in no way detrimental to concrete properties as seen in the issue of inhibitors based on sodium or potassium. Latter study by Skotinck (2000) and Slater (2001) showed that considering long-standing accelerated testing, calcium nitrite was of better quality in terms of strength.
Huang and Yang (1997) investigated the corresponding relationship between the corrosion of reinforced concrete beams and load-carrying capacity. Two beam types of (150 x 150 x 500 mm, reinforced with two 6 mm bottom bars) were used: beams without cracks (type S) and beams with a middle surface crack (type K). Their results showed significant reduction in load-

carrying capacity with the increase in corrosion was more in beams with a low w/c or predetermined cracks (mix B or type K). They concluded that this behavior was a result of the chloride ions having easier access to the reinforcing steel in cracked beams than in un-cracked ones.

Rodriguez *et al.*(1997) studied the level of different corrosion degrees on concrete beams. The studies beam specimens were 200mm by 150mm with a clear span of 2000mm. Beams had both tensile, compressive as well as shear reinforcement that was corroded using accelerated corrosion techniques by immersing the specimens in a solution made of 3% calcium chlorides by weight to the mixing water, over a period of 101-190 days under a constant current density of 100 $\mu A/cm^2$. The results showed that corrosion increases deflections and crack widths at the service load, decreases strength at the ultimate load, and causes an increase in both the spacing and width of transverse cracking due to bond deterioration.

Otunyo and Kennedy (2017) 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 (dacryodes edulis-African Pear). The steel reinforcement members were embedded in concrete and exposed to harsh and saline environments (NaCl solution). Corrosion accelerated test were conducted on uncoated and dacryodes 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 dacryodes 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 (mdacryodes edulis) added strength to the reinforcement.

Torres-Acosta *et al.* (2007) 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. Malumbela *et al.* (2009) studied the combined effects of corrosion and sustained loads of corroded reinforced concrete beam for flexural performance. With the application of a 5% solution of NaCl on an accelerated corrosion process at constant impressed current induced corrosion on tensile steel bars. Beams were tested under self-weight, fewer than 10% of the ultimate load and fewer than 33% of the ultimate load. They concluded that depth of the neutral axis is independent of the level of corrosion for beams free from flexural cracks and beams free from corrosion but notably reduces with an increase in degree of corrosion for corroded beams with flexural crack.

Almusallam (2001) 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**.**

Du *et al.*(2005) 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

2.0 MATERIALS AND METHODS

2.1 Materials

2.1.1 Aggregates

Both fine and coarse aggregates for this research work met the requirements of BS 882. They are gotten from Etche River sand dumpsites in Rivers state, while coarse aggregate are gotten crushed rock siite at Akamkpa.

2.1.2 Cement

Ordinary Portland cement used for all concrete mixes in this investigation. The cement met the requirements of BS EN 196-6

2.1.3 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, University of Uyo, Uyo. Akwa - Ibom State. The water met the requirements of BS 3148

2.1.4 Structural Steel Reinforcement

The reinforcements are gotten directly from the market in Port Harcourt

2.1.5 Corrosion Inhibitors (Resins / Exudates)

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The study inhibitor (Symphonia globulifera linn) of natural tree resins/exudates extracts are gotten from bushes and plantations from Odioku communities, Ahoada West Local Government areas, Rivers State, they are sourced from existing and previously formed and by tapping processes for newer ones.

2.2 METHODS

Present study involves direct application of resins / exudates of trees extract known as inorganic inhibitor (Symphonia globulifera linn), layered/coated on reinforcement steel ribbed surface. The objective of this study was to determine the usefulness of locally available surface-applied corrosion inhibitors under severe corrosive environments and with chloride contamination. The test setup simulates a harsh marine environment of saline concentration.

The samples of reinforced concrete beams of 150 mm x 150 mm × 650 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. The determination of the contribution of the resins will be observed through its adhesive ability with the reinforcement through surface coating application and the bonding relationship between the coated specimens and concrete, its waterproofing and resistive nature (resistance) against accelerator penetration into the bare reinforcement.

2.2.1 Specimen Preparation and Casting of Concrete Beams

Standard method of concrete blend ratio was followed, batching by using weighing materials manually. Ratio of 1:2:4 concrete blend with the aid of weight and water-cement ratio of 0.65. guide mixing turned into used on a easy concrete banker, and mixture was monitored and water brought gradually to achieve best blend design concrete. Preferred uniform shade and consistency concrete was received by way of additions of cement, water and aggregates. The beams were cast in steel mold of size 150mm x 150 mm x 650 mm. sparkling concrete blend for each batch became completely compacted by using tamping rods, to dispose of trapped air, which could reduce the power of the concrete and 12 mm and sixteen mm reinforcements of coated and non-coated had been spaced at a hundred and fifty mm with concrete cover of 25 mm were embedded inside the beam and projection of a hundred mm for half of mobile capacity measurement. Demoulded of specimens was executed after 24 hours and curing lasted for 28 in a curing tanks at room temperature, which then gave manner for extended corrosion take a look at process and testing procedure allowed for 39 days first crack noticed and a further 21 days making a complete of 60 days for in addition observations on corrosion acceleration method.

2.2.2 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 56 beam specimens were tested. After curing for 28 days, 6 controlled beam (non-corroded) was kept in a control state, preventing corrosion reinforcement of the, while 48 beam samples of non-coated and resins / exudates coated were partially place in ponding tank for 39 days placed to examine accelerated corrosion process. After 39 days, the accelerated corrosion subjected samples were examined to determine residual flexural strength. Beam specimen were simply supported on a span of 650mm. 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 . Loads were applied to failure with cracks noticed and corresponding values recorded digitally in a computerized system.

2.2.3 Tensile Strength of Reinforcing Bars

To ascertain the yield and tensile strength of tension bars, bar specimens of 12 mm and 16 mm diameter of non-corroded, corroded and coated were tested in tension in a Universal Testing Machine and were 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.

3.0 RESULTS AND DISCUSSIONS

Results from tables 3.1, 3.2, 3.3 and derived average values from tables 3.4, 3.5 and 3.6 of 27 samples of concrete beam members of non-corroded, corroded and Symphonia globulifera linn (steel bar coated members) with 150µm, 250µm and 350µm, cured for 30 days initial stage and 60 days ponding in saline marine corrosive environment laboratory solution of sodium chloride (NaCl).

Figures 3.1 and 3.4 are plotted flexural failure load versus midspan deflection, figures 3.2, 3.5 and 3.3, 3.6 are graphical representations of ultimate tensile strengths plotted against strain ratios and elongation, demonstrated the behavioral attributes of non-corroded, corrode and resins/ exudates coated concrete beam members in a corrosive environment.

3.1 Non-corroded Concrete Beam Members

Results of non-corroded concrete beams summarized from tables 3.1, 3.2, 3.3, average values are flexural failure load 29.09%, midspan deflection 28.30%, tensile strength 12.30% and elongation 31.50%.

3.2 Corroded Concrete Beam members

Results from tables 3.1, 3.2 and 3.3, the average obtained values for non- corroded beam members on comparison, flexural strength failure load decreases to 22.5 %, midspan deflection increased by 39.30 %, tensile strength decreases to 10.17 % and elongation increased by 46.30 %.

3.3 Symphonia globulifera linn resins/exudates steel coated concrete beam members.

Results comparison of corroded and coated beam members flexural failure load are 22.50% to 29.09%, midspan deflection 39.30% to 31.14%, tensile strength 10.17% to 11.84% and elongation 46.30% to 32.40% respectively. Results showed that corroded beam members decreased in flexural failure load and tensile strength, increased in midspan deflection and elongation. Showing failure rate in low load subjection and higher yield in tensile and elongation.

Flexural Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated specimens)

Table 3.1 : Flexure Strengt Test Results of Non-Corroded (Control) specimens

s/no		Samples								
		A	B	C	D	E	F	G	H	I
Beam		**Non-corroded Control beam**								
Bk1-1	Failure load (KN)	78.08	78.08	77.90	77.87	77.87	77.98	78.68	77.65	78.80
Bk1-2	Midspan deflection (mm)	6.27	6.35	6.95	7.06	6.15	7.09	6.18	6.35	6.15
Bk1-3	Bar diameter (mm)	16	16	16	16	16	16	16	16	16
Bk1-4	Yield Strength, fy (MPa)	460	460	460	460	460	460	460	460	460
Bk1-5	Ultimate Tensile Strength, fu (MPa)	629.3	631.2	629.9	628.7	631.2	629.7	629.5	630.3	628.9
Bk1-6	Strain Ratio	1.35	1.31	1.32	1.35	1.32	1.32	1.32	1.31	1.33
Bk1-7	Elongation (%)	26.05	26.25	26.15	26.22	25.65	25.75	26.25	26.22	26.35

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Table 3.2 : Flexural Strength of Beam Specimens (Non-Corroded, Corroded specimens)

	Corroded beam									
Bk2-1	Failure load (KN)	61.55	62.23	59.80	59.28	61.57	59.57	59.34	61.77	59.55
Bk2-2	Midspan deflection (mm)	9.52	9.35	8.98	8.95	8.55	9.45	8.98	8.58	9.25
Bk2-3	Bar diameter (mm)	16	16	16	16	16	16	16	16	16
Bk2-4	Yield Strength, fy (MPa)	460	460	460	460	460	460	460	460	460
Bk2-5	Ultimate Tensile Strength, fu (MPa)	565.3	561.9	562.5	561.8	561.5	561.8	561.2	562.5	561.8
Bk2-6	Strain Ratio	1.19	1.18	1.18	1.22	1.17	1.19	1.18	1.17	1.17
Bk2-7	Elongation (%)	17.91	18.05	17.72	17.25	18.24	17.53	18.05	17.75	17.76

Table 3.3: Flexural Strength of Beam Specimens (Resin Coated specimens)

3.	Symphonia globulifera linn (steel bar coated specimen)									
Bk3-1	Failure load (KN)	77.85	78.22	77.90	77.98	78.28	77.92	78.08	78.28	78.52
Bk3-2	Midspan deflection (mm)	7.39	7.05	7.29	7.04	6.49	7.18	6.64	6.49	6.48
Bk3-3	Bar diameter (mm)	16	16	16	16	16	16	16	16	16
Bk3-4	Yield Strength, fy (MPa)	460	460	460	460	460	460	460	460	460
Bk3-5	Ultimate Tensile Strength, fu (MPa)	629.8	629.6	630.2	630.1	629.2	629.6	630.1	631.2	629.6
Bk3-6	Strain Ratio	1.31	1.30	1.31	1.32	1.30	1.30	1.32	1.32	1.33
Bk3-7	Elongation (%)	26.52	26.59	26.53	26.53	26.54	26.56	26.73	26.74	26.76

Table 3.4: Average Flexural Strength of Beam Specimens (Non-Corroded Specimens)

1A		Non-Corroded beam		
Bk1A-1	Failure load (KN)	78.07	78.01	78.37
Bk1A-2	Midspan deflection (mm)	6.52	6.76	6.22
Bk1A-3	Bar diameter (mm)	16	16	16
Bk1A-4	Yield Strength, fy (MPa)	460	460	460
Bk1A-5	Ultimate Tensile Strength, fu (MPa)	630.1	629.8	629.4
Bk1A-6	Strain Ratio	1.32	1.33	1.32
Bk1A-7	Elongation (%)	26.15	25.87	26.27

Table 3.5: Average Flexural Strength of Beam Specimens (Corroded Specimens)

2A		**Corroded beam**		
Bk2A-1	Failure load (KN)	61.19	60.14	60.22
Bk2A-2	Midspan deflection (mm)	9.28	8.98	8.93
Bk2-3	Bar diameter (mm)	16	16	16
Bk2A-4	Yield Strength, fy (MPa)	460	460	460
Bk2A-5	Ultimate Tensile Strength, fu (MPa)	563.2	561.7	561.8
Bk2A-6	Strain Ratio	1.18	1.19	1.17
Bk2A-7	Elongation (%)	17.89	17.67	17.85

Table 3.6: Average Flexural Strength of Beam Specimens (Resin Coated specimens)

3A		**Symphonia globulifera linn (steel bar coated specimen)**		
		150µm) coated (A)	**(250µm) coated(B)**	**(350µm) coated (C)**
Bk3A-1	Failure load (KN)	77.99	76.37	78.29
Bk3A-2	Midspan deflection (mm)	7.24	7.18	7.55
Bk3A-3	Bar diameter (mm)	16	16	16
Bk3A-4	Yield Strength, fy (MPa)	460	460	460
Bk3A-5	Ultimate Tensile Strength, fu (MPa)	629.8	629.6	630.3
Bk3A-6	Strain Ratio	1.31	1.31	1.32
Bk3A-7	Elongation (%)	26.54	26.56	26.74

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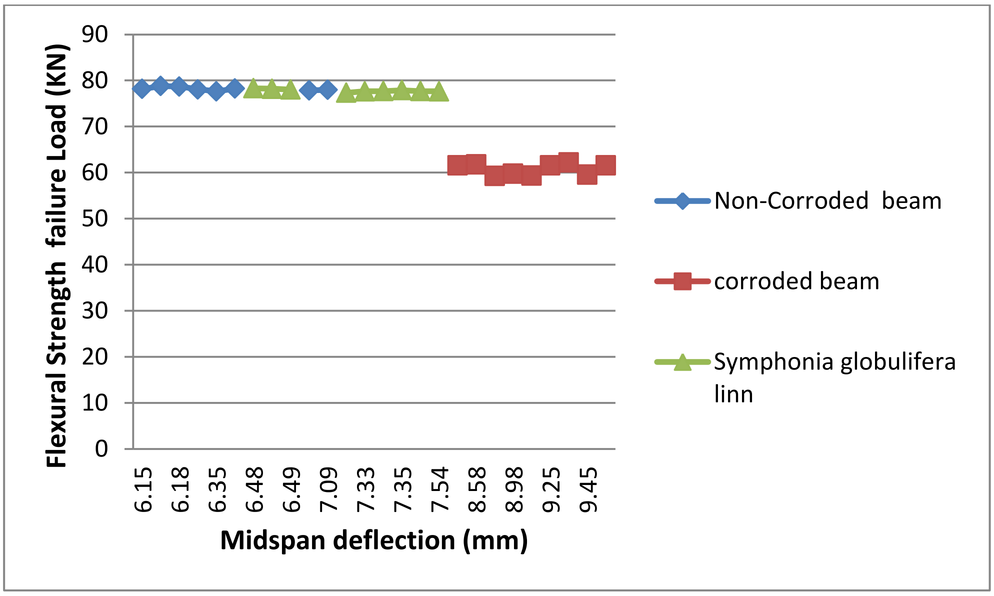

Figure 3.1: Failure Load versus Midspan deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens

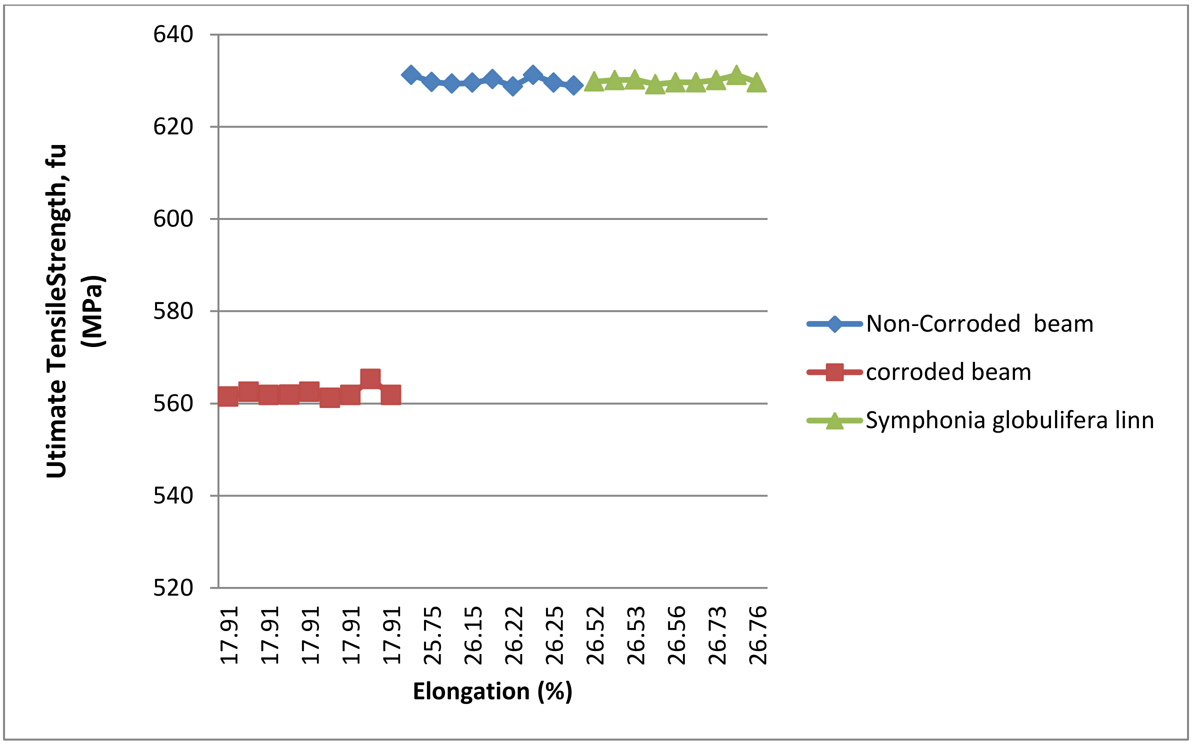

Figure 3.2: Ultimate Tensile Strength versus Elongation of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

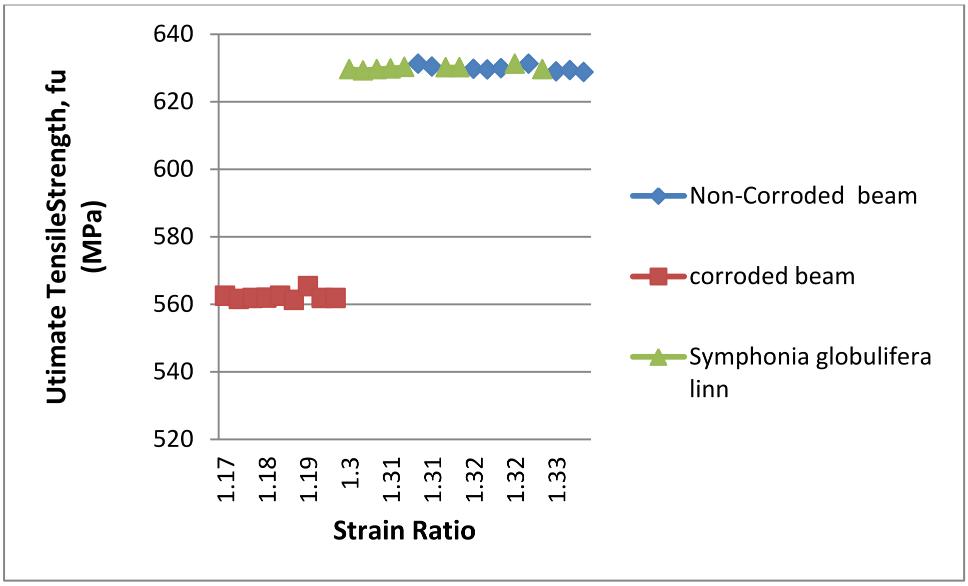

Figure 3.3: Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

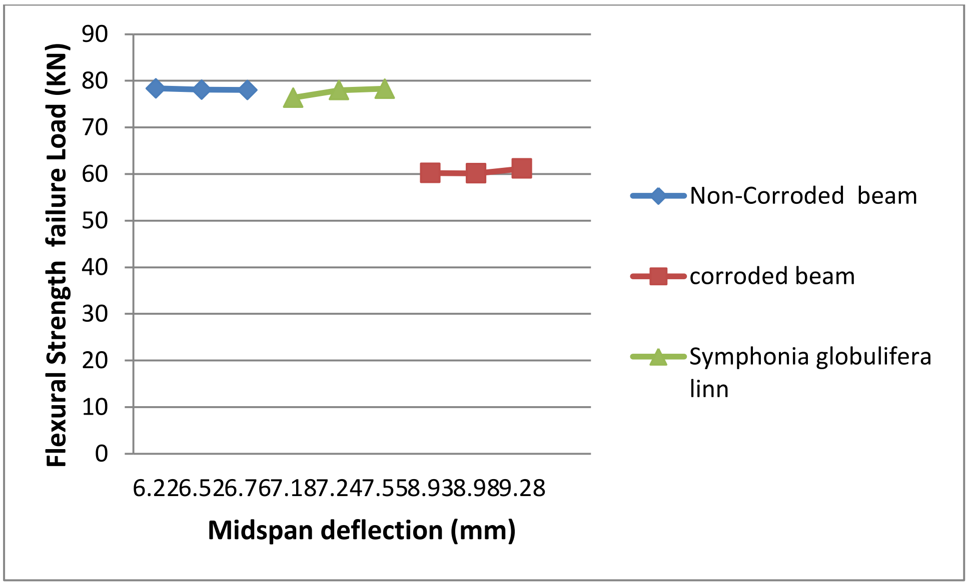

Figure 3.4: Average Failure Load versus Midspan deflection of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

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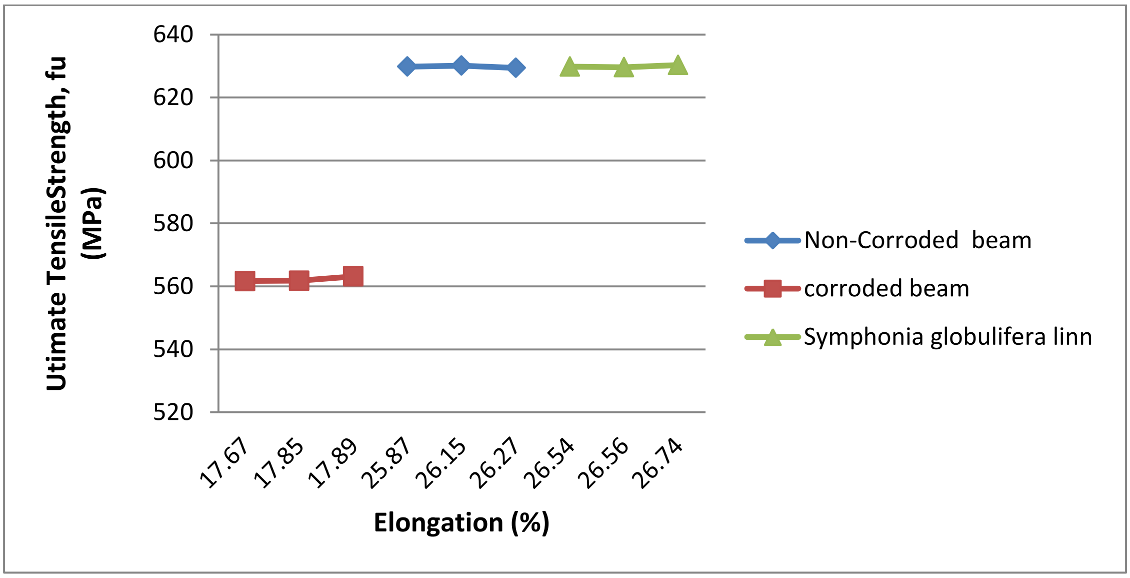

Figure 3.5: Average Ultimate Tensile Strength versus Elongation of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

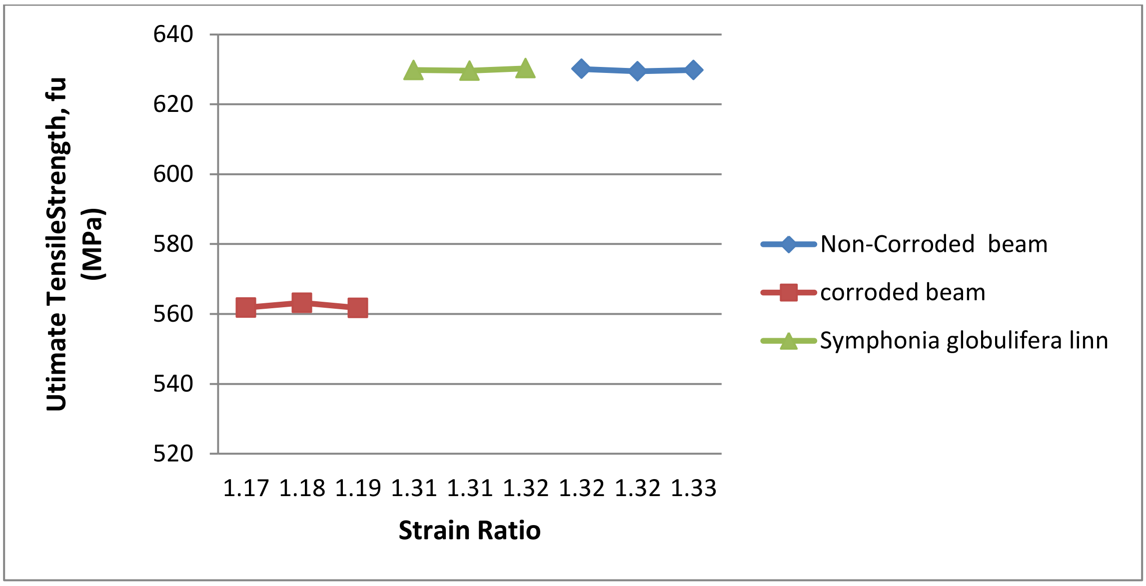

Figure 3.6: Average Ultimate Tensile Strength versus Strain Ratio of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

4.0 CONCLUSIONS

Results from tables 3.1 – 3.6 and figures 3.1 – 3.6, the below conclusions were drawn:

- Resins / exudates coated members showed higher failure load with low deflection.
- Presence of corrosion potential noticed with severe signs of cracks, pitting and spalling
- results showed decreased in failure load and tensile strength of corroded members while increased in midspan deflection and elongation
- Resins/exudates coated concrete members resisted corrosion attack
- Changes in surface condition of steel bar was observed

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