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Comparative Residual Yield Strength Structural Capacity of Non-corroded, Corroded and Inhibited Reinforcement Embedded in Reinforced Concrete Structure and Exposed to severely Medium

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Abstract

This study investigated the residual yield strength structural capacity effect of non-corroded, corroded and inhibited steel bar. Three trees extract resins / exudates paste of Symphonia globulifera linn, ficus glumosa and acardium occidentale l were directly coated to reinforcement with 150µm, 250µm and 350µm thicknesses, embedded into concrete beam and initially cured for 30days in clean tap water and exposed to corrosive pond for 60 days for corrosion acceleration. Results obtained showed that corrosion potential was recorded on uncoated reinforcement with cracks propagations while resin coated showed resistance. 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.

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

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1.0 Introduction

Corrosion rate of steel reinforcement in concrete is strongly affected by a number of environmental parameters including the presence of oxygen and moisture, concrete permeability and concrete cover, pH of the pore solution and gradients in chloride levels. High compressive strength concrete (low water/cement ratio) allowed permeability which minimizes corrosion of steel by reducing penetration of such corrosion inducing ingredients as CO_2 , chlorides and moisture. These environmental parameters 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. The use of corrosion-inhibitors is one of the techniques and approach to curb, prevent or reduce the corrosion of steel. Majority of the inhibitors for steel reinforcements are used in conditions of acidic or neutral stages, while very rapid attack is experienced in and uninhibited steel; same way, corrosion of steel under the alkaline conditions in concrete is very slow.

Macdonald [1] 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 [2] 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 [3] and Slater [4] showed that considering long-standing accelerated testing, calcium nitrite was of better quality in terms of strength.

The use of organic compounds to inhibit corrosion of mild steel and iron has assumed great significance due to their application in preventing corrosion under various corrosive environments Ali *et al*., [5]. The development of corrosion inhibitors is based on organic compounds containing nitrogen, oxygen, sulfur atoms and multiple bonds in the molecules that facilitate adsorption on the metal surface Cruz *et al*., [6]. The use of these natural products such as extracted compounds from leaves or seeds as corrosion inhibitors have been widely reported by several authors (El-Etre, [7], [8]; Gunasekaran and Chauhan, [9]; Moretti *et al*., [10]; El-Etre *et al*., [11]; Ismail, [12]; Ashassi-Sorkhabi and Asghari, [13]; Raja and Sethuraman, [14], [15], [16], [17]; Oguzie, [18]; Okafor *et al*., [19]; Eddy, [20]; Ostovari *et al*., [21]; Satapathy *et al*., [22]; Olusegun and James, [23]).

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 [24]

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 [25]

2.1.4 Structural Steel Reinforcement

The reinforcements are gotten directly from the market in Port Harcourt.

2.1.5 Corrosion Inhibitors (Resins / Exudates) Symphonia globulifera linn, Ficus glumosa, Acardium occidentale l.

The study inhibitors are of natural tree resins/Exudates substances extracts. They are abundantly found in Rivers State bushes and they are sourced from plantations and bushes of Odioku communities, Ahoada West Local Government areas, Rivers State, from existed and previously formed and by tapping processes for newer ones. They are:

1. Symphonia globulifera linn
2. Ficus glumosa
3. Acardium occidentale l.

2.2 METHODS

Present study involves direct application of resins / exudates of trees extract known as inorganic inhibitor (Symphonia globulifera linn, ficus glumosa and acardium occidentale l), 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 45 beam specimens was tested. After curing for 28 days, 6 controlled beam (non-corroded) was kept in a control state, preventing corrosion reinforcement of the, while 18 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 specimens 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. Load was 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 table 3.1 showed the randomly concrete beam members A – I and table 3.2, the derived computed percentile values from table 3.1 of 45 samples of non-corroded, corroded and resins / exudates coated steel bar of thicknesses 150µm,(ABC), 250µm (DEF) and 350µm (of trees extract of (Symphonia globulifera linn, ficus glumosa and acardium occidentale l.). Figures 3.1 and 3.4 are the plots of the entire and averaged flexural strength failure load versus deflection for non-corroded, corroded and Symphonia globulifera linn, ficus glumosa and acardium occidentale l.) resins/exudates steel coated beam beams. Figures 3.3, 3.5 and 3.3, 3.6 are the plots of ultimate tensile strengths versus elongations / strain ratios of general samples and average values derived from table 3.1.

3.1 Non-corroded Concrete Beam members

Tables 3.2 enumerated the results of non-corroded concrete beams at flexural strength failure load, midspan deflection, tensile strength, and elongation as 29.09%, 28.30%, and 12.30% 31.50%.

3.2 Corroded Concrete Beam members

Results from table 3.1 and summarized average computed values in table 3.2, the percentile values for flexural strength failure load, midspan deflection, tensile strength and elongation are 22.5 %, 39.30 %, 10.17 % and 46.30 %.

3.3 Symphonia globulifera linn, Ficus glumosa and Acardium occidentale l coated steel Bar Concrete Beam Members

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.

Table 3.1: Summary Results Flexural Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens)

		Beam samples								
s/no		Failure load (KN)								
		A	B	C	D	E	F	G	H	I
BkA1-1	**Non-corroded Control Cube**	78.08	78.25	77.90	77.87	78.18	77.98	78.68	77.65	78.80
BkA1-2	**Corroded**	61.55	62.23	59.80	59.28	61.57	59.57	59.34	61.77	59.55
	Coated Specimens	**(150µm coated) ABC**			**(250µm coated) DEF**			**(350µm coated) GHI**		
BkA1-3	**Ficus glumosa (steel bar coated specimen)**	77.35	78.30	77.65	77.69	78.05	77.88	77.65	77.69	78.19
BkA1-4	**Symphonia globulifera linn (steel bar coated specimen)**	77.85	78.22	77.90	77.98	78.28	77.92	78.08	78.28	78.52
BkA1-5	**Acardium occidentale l (steel bar coated specimen)**	78.35	77.85	77.72	77.15	78.28	77.88	78.15	78.28	78.28
2		**Midspan deflection (mm)**								
BkB2-1	**Non-corroded Control Cube**	6.27	6.35	6.95	7.06	6.15	7.09	6.18	6.35	6.15
Bk B2-3	**Corroded**	9.52	9.35	8.98	8.95	8.55	9.45	8.98	8.58	9.25

BkB2-3	**Ficus glumosa(steel bar coated specimen)**	7.25	6.65	7.54	7.35	6.91	7.35	7.33	7.33	6.90
BkB2-4	**Symphonia globulifera linn (steel bar coated specimen)**	7.39	7.05	7.29	7.04	6.49	7.18	6.64	6.49	6.48
BkB2-5	**Acardium occidentale l. (steel bar coated specimen)**	6.95	7.24	7.36	7.36	7.02	7.32	7.15	7.10	7.08
3	**Utimate Tensile Strength, fu (MPa)**									
BkC3-1	**Non-corroded Control Cube**	629.3	631.2	629.9	628.7	631.2	629.7	629.5	630.3	628.9
BkC3-2	**Corroded**	565.3	561.9	562.5	561.8	561.5	561.8	561.2	562.5	561.8
BkC3-3	**Ficus glumosa (steel bar coated specimen)**	630.0	630.9	630.5	630.5	630.5	630.5	630.1	630.6	630.6
BkC3-4	**Symphonia globulifera linn (steel bar coated specimen)**	629.8	629.6	630.2	630.1	629.2	629.6	630.1	631.2	629.6
BkC3-5	**Mangifera indica(steel bar coated specimen)**	629.4	630.4	630.7	631.4	629.6	629.9	630.0	629.6	629.6
	Strain Ratio									
BkD4-1	**Non-corroded Control Cube**	1.35	1.31	1.32	1.35	1.32	1.32	1.32	1.31	1.33
BkD4-2	**Corroded**	1.19	1.18	1.18	1.22	1.17	1.19	1.18	1.17	1.17
BkD4-3	**Ficus glumosa (steel bar coated specimen)**	1.31	1.33	1.31	1.30	1.30	1.30	1.29	1.31	1.32
BkD4-4	**Symphonia globulifera linn (steel bar coated specimen)**	1.31	1.30	1.31	1.32	1.30	1.30	1.32	1.32	1.33
BkD4-5	**Acardium occidentale l. (steel bar coated**	1.31	1.30	1.30	1.30	1.31	1.30	1.30	1.30	1.31

	specimen)									
5					**Elongation (%)**					
BkE5-1	**Non-corroded Control Cube**	26.05	26.25	26.15	26.22	25.65	25.75	26.25	26.22	26.35
BkE5-2	**Corroded**	17.91	18.05	17.72	17.25	18.24	17.53	18.05	17.75	17.76
BkE5-3	**Ficus glumosa (steel bar coated specimen)**	26.23	26.85	26.33	26.30	26.75	26.53	26.44	26.15	26.81
BkE5-4	**Symphonia globulifera linn (steel bar coated specimen)**	26.52	26.59	26.53	26.53	26.54	26.56	26.73	26.74	26.76
BkEE-5	**Acardium occidentale l. (steel bar coated specimen)**	26.38	26.27	26.30	26.25	26.33	26.23	26.35	26.35	26.33

Table 3.2: Summary Results of Average Flexural Strength of Beam Specimens (Non-Corroded, Corrode and Resins Coated Specimens)

			Failure load (KN)	
1				
BkA1-1	**Non-corroded Control Cube**	78.07	78.01	78.37
BkA1-2	**Corroded**	61.19	60.14	60.22
			Coated specimens	
		(150µm) coated (A)	**(250µm) coated(B)**	**(350µm) coated (C)**
BkA1-3	**Ficus glumosa (steel bar coated specimen)**	77.76	77.87	77.84
BkA1-4	**Symphonia globulifera linn (steel bar coated specimen)**	77.99	76.37	78.29
BkA1-5	**Acardium occidentale l. (steel bar**	77.97	77.77	78.23

	coated specimen)			
		Midspan deflection (mm)		
BkB2-1	**Non-corroded Control Cube**	6.52	6.766	6.22
BkB2-2	**Corroded**	9.28	8.98	8.93
BkB2-3	**Ficus glumosa (steel bar coated specimen)**	7.14	7.20	7.18
BkB2-4	**Symphonia globulifera linn (steel bar coated specimen)**	7.24	7.18	7.55
BkB2-5	**Acardium occidentale l. (steel bar coated specimen)**	7.18	7.23	7.11
3		**Utimate Tensile Strength, fu (MPa)**		
BkC3-1	**Non-corroded Control Cube**	630.1	629.8	629.4
BkC3-2	**Corroded**	563.2	561.7	561.8
BkC3-3	**Ficus glumosa (steel bar coated specimen)**	630.4	630.5	630.43
BkC3-4	**Symphonia globulifera linn (steel bar coated specimen)**	629.8	629.6	630.3
BkC3-5	**Acardium occidentale l. (steel bar coated specimen)**	630.1	630.3	629.7
4		**Strain Ratio**		
BkD4-1	**Non-corroded Control Cube**	1.32	1.33	1.32
BkD4-2	**Corroded**	1.18	1.19	1.17
BkD4-3	**Ficus glumosa (steel bar coated specimen)**	1.31	1.3	1.30
Bk4-4	**Symphonia globulifera linn (steel bar coated specimen)**	1.31	1.31	1.32
BkD4-5	**Acardium occidentale l. (steel bar coated specimen)**	1.30	1.30	1.30

5		Elongation (%)		
BkE5-1	**Non-corroded Control Cube**	26.15	25.87	26.27
BkE5-2	**Corroded**	17.89	17.67	17.85
BkE5-3	**Ficus glumosa (steel bar coated specimen)**	26.47	26.52	26.46
BkE5-4	**Symphonia globulifera linn (steel bar coated specimen)**	26.54	26.56	26.74
BkE5-5	**Acardium occidentale l. (steel bar coated specimen)**	26.31	26.27	26.34

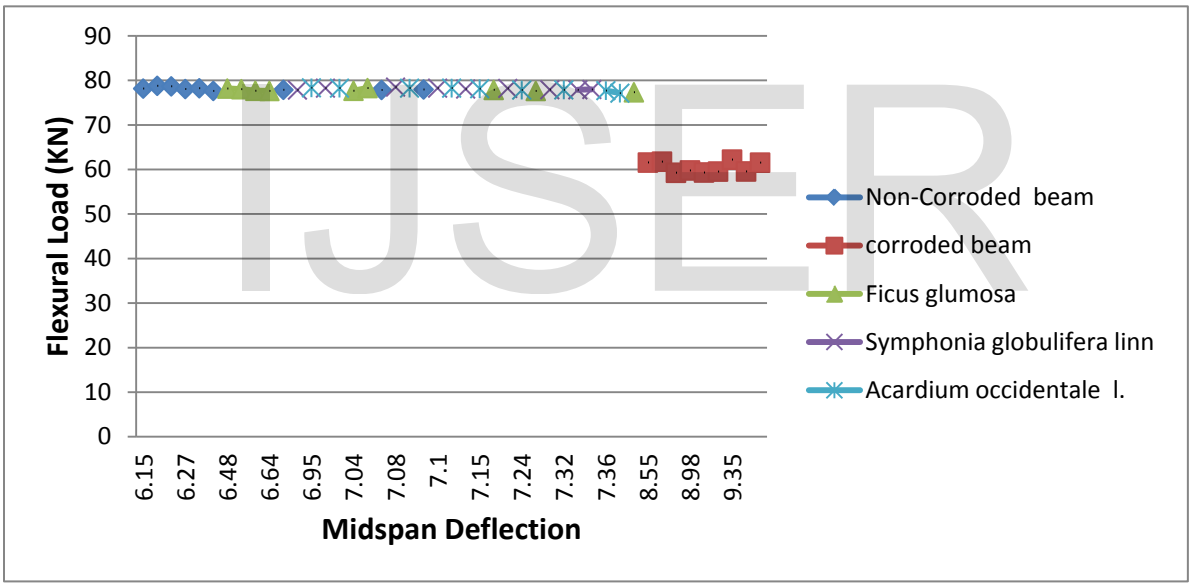

Figure 3.1: Summary Results of Flexural Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens) Flexural Load vs Midspan Deflection

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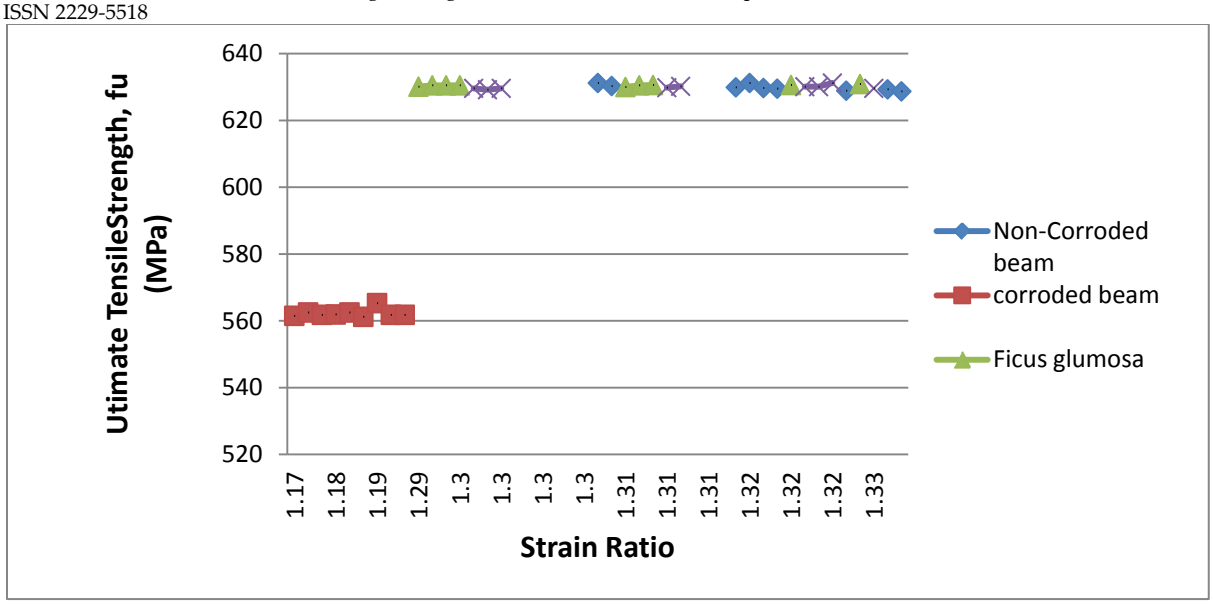

Figure 3.2: Summary Results of Flexural Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens) Midspan Deflection vs Strain Ratio

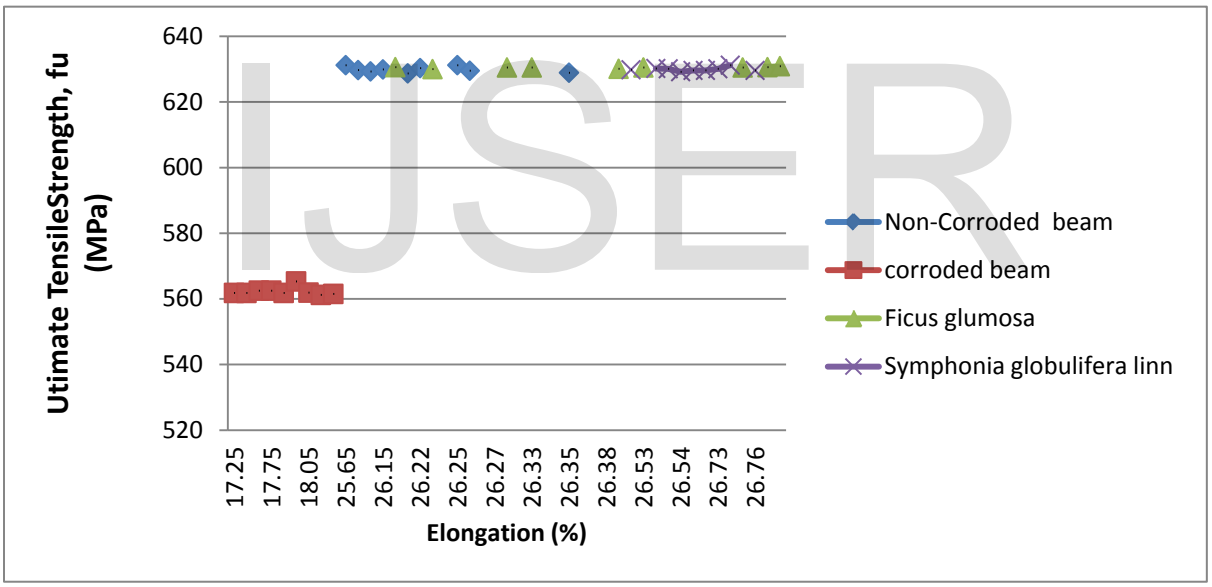

Figure 3.3: Summary Results of Flexural Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens) Ultimate Tensile Strength vs Elongation

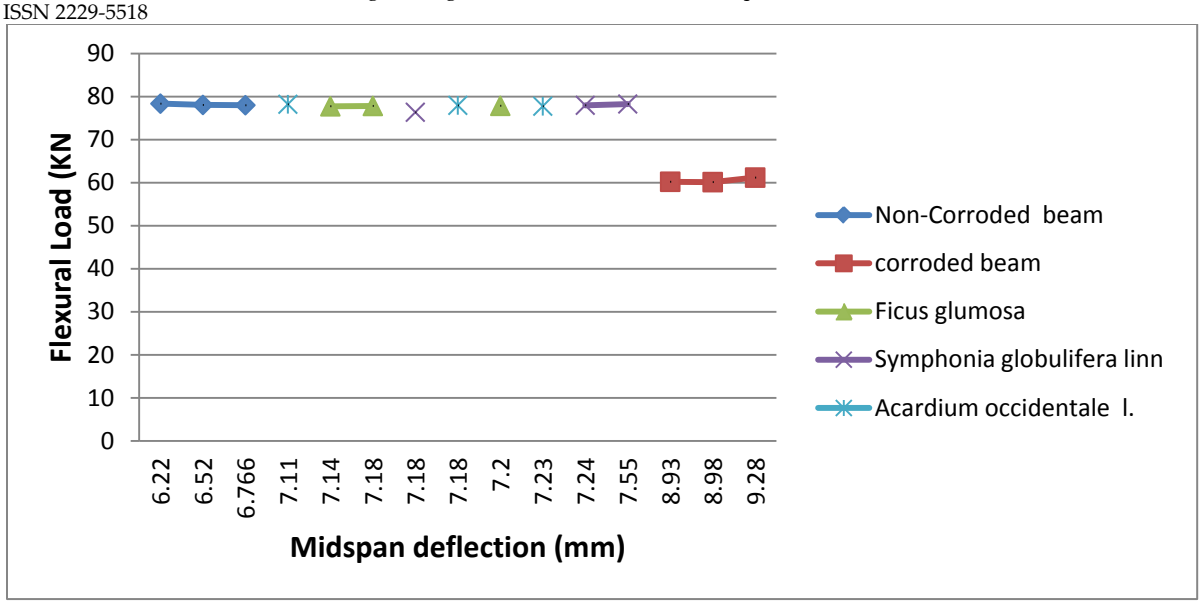

Figure 3.4: Average Results of Flexural Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens) Flexural Load vs Midspan Deflection

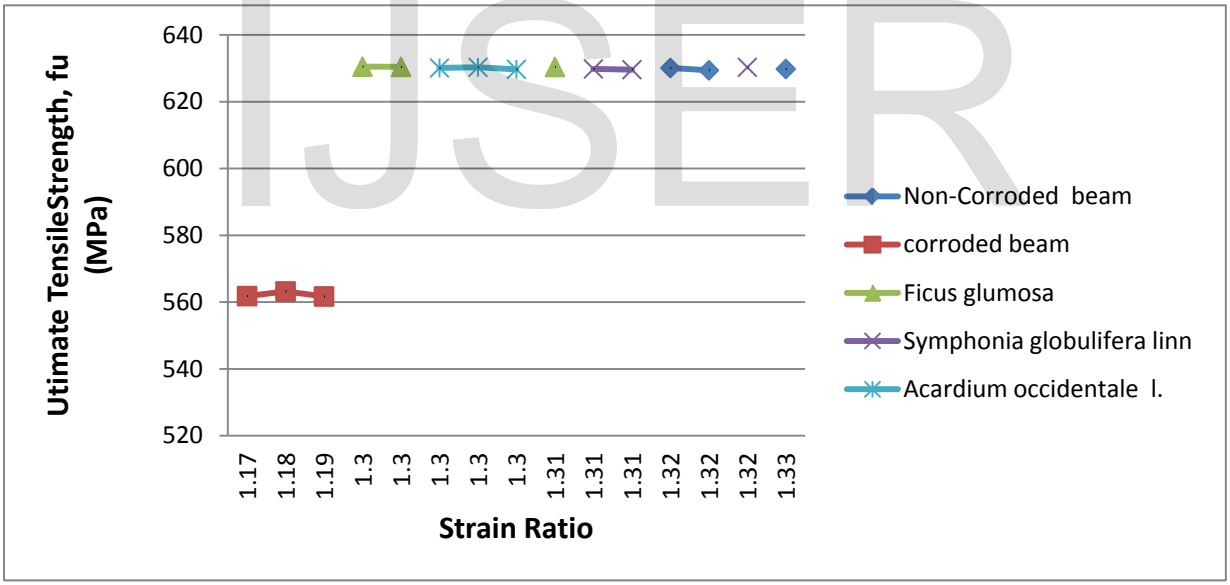

Figure 3.5: Average Results of Flexural Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens) Ultimate Tensile Strength vs Elongation

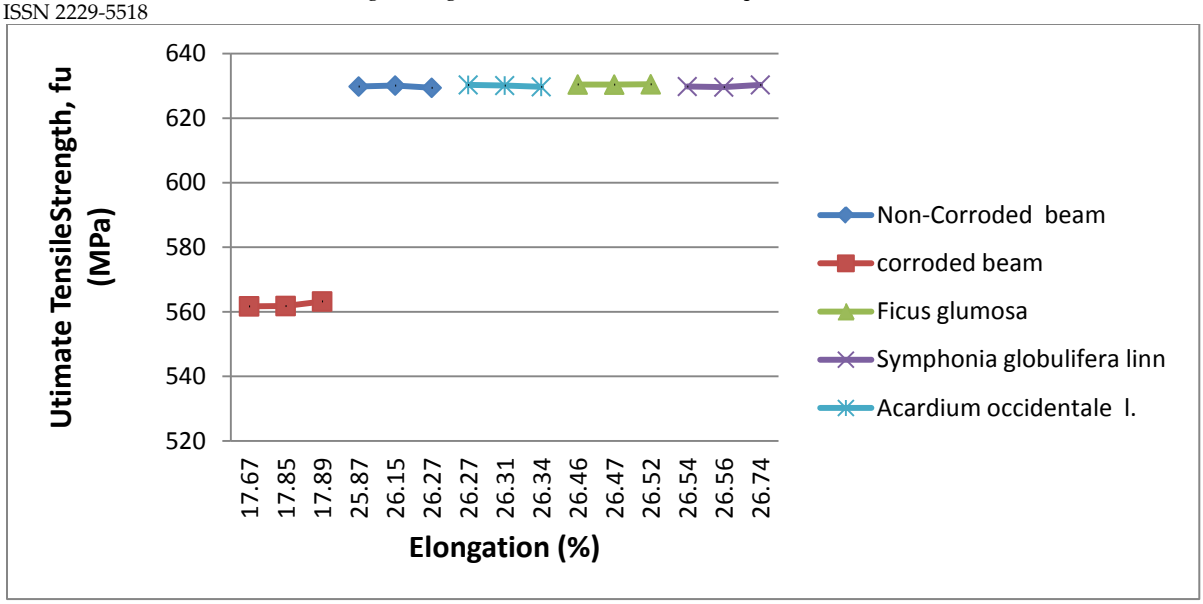

Figure 3.6: Average Results of Flexural Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated Specimens) Ultimate Tensile Strength vs Strain Ratio

4.0 Conclusions

The experimental investigations presented in table 3.0 showed that:

i. The presence of localized pitting was noticed in corroded compared to non-corrode and coated specimens. Significant changes occurred on the surface conditions of the reinforcing steel as the mechanical properties of the steel were adversely affected.

ii. Corrosion of reinforcement resulted in a decrease of the residual yield stress.

iii. Investigated inhibitors do not add strength to reinforcement in flexural strength test; rather, it sustained the strength reduction by maintaining actual state

iv. Residual strength comparison of non-corroded, corroded and resin / exudated coated steel bars showed reasonably noticed as flexural failure load was lesser in corroded specimens

v. Significant changes occurred on the surface conditions of the reinforcing steel as the mechanical properties of the steel were adversely affected.

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