EFFECT OF CORROSION ON FLEXURAL RESIDUAL STRENGTH AND MID-SPAN DELECTION OF STEEL (COATED WITH RESINS/EXUDATES OF TREES) REINFORCED CONCRETE BEAMS UNDER SODIUM CHLORIDE MEDIUM

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Abstract
This study was carried out to investigate 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 showed that corrosion potential was recorded on uncoated steel reinforcement with cracks propagations while resin coated showed resistance to corrosion. For the corroded steel reinforcement members, result of flexural strength test of failure loads was lower than the dacryodes edulis coated and non-corroded steel reinforcement members, while mid-span deflection was higher for the corroded steel reinforcement members compared to the non- corroded and dacryodes edulis coated stel reinforcement members. Tensile test results showed that maximum yield and ultimate loads are higher also in non-corroded (controlled) and coated steel reinforcement. 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%.. Similar results were obtained for the flexural failure strength, elongation and mid-span deflection for the (the resin coated and non-corroded steel members).. For the corroded beam members, the flexural faiure strength and elongation increased by 23% and 32% respectively, while the mid-span deflection decreased by 40%.. The resin (mdacryodes edulis) added strength to the reinforcement.

Results also showed that corroded specimens affected flexural strength of reinforcement. Investigated inhibitors do not add strength to reinforcement in flexural strength test.

Key Words: Steel Reinforced Concrete, Corrosion, resins (inorganic inhibitors), flexural strength.

1.0 Introduction

Corrosion of steel reinforcement is generally the most important factor that cuts the service life of reinforced concrete structures subjected to cruel and harsh environments as found mostly in marine environments all over the world. A major cause of steel reinforcement corrosion is the presence of chlorides, from chloride contaminated aggregates and chloride containing admixtures used during construction; or from penetration of chloride ions from sea spray, or ingress of de-icing salt.

Ting and Nowak [1] established that the carrying capacity of a reinforced concrete beam lies purely on the strength of steel reinforcement. In this, the loss of steel reinforcement area is likely at risk and special attention may be required or put into consideration. Corrosion is one of the important causes of steel area loss. The strength reduction due to the reinforcing steel area loss is a linear function of the loss of material.

Fu and Chung [2] also concluded that corrosion is one of the main causes of the limited durability of reinforced concrete.

Huang and Yang [3]] carried out experiments on corroded reinforced concrete beams of determined cracks, in order to study the result of reinforcing steel area loss on flexural actions of reinforced concrete beams.

Ting and Nowak [1] formulated the outcome of reinforcing steel area loss calculations from mechanical damages resulting from reinforcing steel loss due to corrosion on the load carrying capacity of beams of corrosion presence. The procedure evaluated and demonstrated the effect of loss of reinforcing steel area of a typical reinforced concrete bridge girder. Based on their formulation and approach, the reinforcing steel area loss is a linear function of the loss of material.

Uomoto and Misra [4] established a different method which established that the cause of structural deterioration resulting from the reinforcement corrosion is indirectly interrelated to the loss of strength of the bars resulting from cross-sectional area reduction, caused by factors like crack development in concrete and bond could lead to greater reduction loss of strength of the structure.

The load carrying capacity of RC beams decreased as the corrosion product increased. The loss of reinforcing load carrying capacity was calculated to ascertain percentage reduction of the steel bar diameter resulting from corrosion. Experimental results showed that loading capacity was reduced by 10%.

Yoon et al.[5] investigated concrete beam specimens reinforced with a single standard Grade 60 reinforcing steel bar. An epoxy was applied (coated) on the reinforcing steel bar to reduce or curb corrosion potential and the effect of steel corrosion was examined, the flexural loading capacity of the concrete beams decreased as the percentage weight loss of the reinforcing steel increased indicating that the loss of the loading capacity might be primarily due to the loss of steel-concrete bond, the lower the remaining load carrying capacity of a beam, the clearer the steel-concrete bond failure was seen from the flexure testing.

Cabrera [6] experimented on six corroded beams reinforced with top and bottom bars of two 10 mm and 12 mm plain top bars, with shear links of 8 mm at 40 mm spacing, as a web reinforcement along the shear span of 384 mm. Around 2% chloride was added to the concrete to accelerate the corrosion process. The amount of steel loss was estimated by the gravimetric mass-loss method. When the percent mass loss was smaller than 2%, the moment capacity increased by almost 20%, an approximately linear decrease occurred in the moment capacity when the percent of mass loss increased. Rodriguez et al [7] experimented on reinforced concrete beams under corrosion-acceleration stage. They found that the experimental value of the bending moment at maximum load, in beams with only bottom bars corroded, was close to the calculated value, using the reduced section of the bottom bars.

Pandian and Mathur [8] established the use of natural products as corrosion inhibitor for metals in corrosive media.

Rasheeduzzafar et al [9] concluded from their study that the cover over reinforcement has the most significant effect on the extent of rebar corrosion.

Rasheeduzzafar et al [10] recommended the following concrete cover for structures serving in various environment of the Arabian Gulf as follows:

(i) Building components which are permanently exposed to the salt-laden corrosive atmosphere -2 inches.

(ii) Building components which are protected against weather and the aggressive condition of exposure: 1.0 to 1.5 inches.

(iii) Concrete components exposed to sea water and footings as well as other main structural members cast against the ground: 3.0 inches.

2.0 MATERIALS AND METHODS

The present study involves direct application of resins / exudates of trees extract known as inorganic inhibitor as coating on the reinforcing steel surface. Dacryodes edulis (Native Pear, also called UBE in Ibo Language) was the resin used. The main objective of this study was to determine the effectiveness of a locally available surface-applied corrosion inhibitors (dacryodes edulis) under severe corrosive environments and with chloride contamination. The test setup simulates a harsh marine environment of saline concentration in the concrete in the submerged portion of the test specimens since corrosion activity of the steel cannot be sustained in fully immersed samples. The samples were designed with sets 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 electrochemical corrosion test and flexural test for beam, and was investigated. To simulate the ideal corrosive environment, concrete samples were immersed in solutions (NaCl) and the depth of the solution was maintained.

This study involved the direct application of paste of a resin- dacryodes edulis (African Pear) which is abundantly available in Nigeria on steel reinforced concrete beam members subjected to a corrosive environment- Sodium Chloride (Nacl) for a period of 60 days and then testing for the flexural failure load, mid-span deflection and elongation of the reinforcement steel. In order to observe the effectiveness of the dacryodes edulis

(Africa Pear) as a corrosion inhibitor that is capable of sustaining the flexural strength, mid-span deflection and elongation of a reinforced concrete beam member subjected to a corrosive medium.

2.0 MATERIALS AND METHODS

2.1 Materials

2.1.1 Aggregates

The fine aggregate used was washed sand deposit and was obtained from Imo River, in Oyigbo Local Government Area of Rivers State. Coarse aggregate was granite a crushed rock of 12 mm size and of high quality. Both aggregates met the requirements of BS 882. [11]

2.1.2 Cement

The cement used was Eagle Portland Cement, it was used for all concrete mixes in this investigation. The cement met the requirements of BS EN 196-6 [12].

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.

2.1.4 Structural Steel Reinforcement

The reinforcements were obtained directly from the market in Port Harcourt.

2.1.5 Corrosion Inhibitors (Resins / Exudates) Dacryodes edulis (African Pear) UBE

The study inhibitor (Dacryodes edulis (African Pear) UBE, of natural tree resins/Exudates substance 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.

2.2 METHOD

2.2.1 Sample preparation for steel reinforcement.

Corrosion tests were performed on high yield steel (reinforcement) of 16 mm diameter with 700 mm lengths of beams, Specimen surfaces roughness was treated with sandpaper /wire brush and specimens were cleaned with distilled water, washed by acetone and dried properly, then polished and coated with dacryodes edulis (african pear Ube), resin pastes with coating thicknesses of 150µm, 250µm and 300µm before corrosion test. The test cubes and beams were cast in steel mould of size 150mm x 150 mm x 650 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 slab and projection of 100 mm for half cell potential measurement. Specimens were demoulded after 24hrs and cured for 28 days. The specimens were cured at room temperature in the curing tanks which then gave way for accelerated corrosion test process and testing procedure allowed for 39 days first crack noticed and a further 21 days making a total of 60 days for further observations on corrosion acceleration process.

2.2.2 Flexure testing of Beam Specimens

The performance of the Flexural Test on the Concrete Beams was carried out on 54 specimens on Universal Testing Machine in accordance with BS EN 12390- 5[13] After curing for 28 days, 6 controlled beam (non-corroded) was kept in a control state, preventing corrosion reinforcement of the steel beams, while 48 beam samples of non-coated and resin / exudated coated were partially place in ponding tank for 39 days and a further 21 days making a total of 60 days placed to examine accelerated corrosion process. After 60 days, the accelerated corrosion subjected samples were examined to determine residual flexural strength. Each specimen was simply supported over an effective span of 650mm. The flexure tests were conducted using an Instron Universal Testing Machine of 100KN capacity at a slow loading rate of 1 mm/min. The beams were tested in flexure under third point loading. The loads were applied at third points between the supports on top of the beam at a distance of 150mm from each support. The loads were applied on the beam until the first crack was noticed and the corresponding deflections were recorded until the final collapse of the beam was reached. The load and mid-span deflection data for each specimen was recorded using a computerized data acquisition system at pre-determined load intervals till failure. The data so generated was utilized to plot load-deflection curves for each of the tested specimens. Specimens of 150 mm x150 mm x150 mm concrete cube specimens were also prepared from the same concrete mix used for the beams cured in water for 28 days, and accelerated with 5% NaCl solution for same 39 days and a further 21 days making a total of 60 days were consequently tested to determine the compressive strength.

3.0 RESULTS AND DISCUSSIONS

Figure 1 is the graph of the flexural strength failure load versus the mid-span deflection for the corroded, non-corroded and dacryodes edulis steel reinforced members. The same result is plotted as a bar chat in

Figure 2. Figure 3 is a plot of the tensile strength versus the elongation of the steel reinforcement for the corroded, non-corroded and dacryodes edulis steel reinforcement members, while Figure 4 is the same result plotted as a bar chat.
From Tables 1, 2 and 3, and figures 1, 2, 3 and 4, the following observations were made:

Table 1 : Flexural Strength Test Results of Beam Specimens (Non-Corroded, Corrode and Resin Coated specimens, including elongation and tensile strength)

Flexure Test Results of Control, Corroded and Resin/exudate Coated Beams.										
s/no	Samples									
		A	B	C	D	E	F	G	H	I
Beam	**Non-corroded Control beam**									
Bk1-1	Failure load (KN)	78.08	78.25	77.90	77.87	78.18	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	Utimate 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
2	**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	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
Coated thickness										
		(150µm) coated			(250µm) coated			(350µm) coated		
3	**Dacryodes edulis (steel bar coated specimen)**									
Bk3-1	Failure load (KN)	78.35	78.40	77.98	78.08	77.65	77.98	78.68	78.15	78.75
Bk3-2	Midspan deflection (mm)	6.29	6.38	6.77	7.12	7.19	7.25	6.62	6.79	6.18
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	Tensile Strength, fu (MPa)	630.1	630.7	631.9	630.5	631.1	629.8	629.5	631.6	631.8
Bk3-6	Strain Ratio	1.32	1.30	1.31	1.33	1.30	1.30	1.31	1.32	1.33
Bk3-7	Elongation (%)	26.59	26.52	26.33	26.35	25.98	26.78	26.35	26.18	26.35

Table .2 : Average Flexural Strength of Beam Specimens (Non-Corroded, Corrode and Resin Coated specimens)

1	**Non-Corroded beam**			
Bk1-1	Failure load (KN)	78.07	78.01	78.37
Bk1-2	Midspan deflection (mm)	6.52	6.766	6.22
Bk1-3	Bar diameter (mm)	16	16	16
Bk1-4	Yield Strength, fy (MPa)	460	460	460
Bk1-5	Tensile Strength, fu (MPa)	630.1	629.8	629.4
Bk1-6	Strain Ratio	1.32	1.33	1.32
Bk1-7	Elongation (%)	26.15	25.87	26.27
	Corroded beam			
Bk2-1	Failure load (KN)	61.19	60.14	60.22
Bk2-2	Midspan deflection (mm)	9.28	8.98	8.93
Bk2-3	Bar diameter (mm)	16	16	16
Bk2-4	Yield Strength, fy (MPa)	460	460	460
Bk2-5	Tensile Strength, fu (MPa)	563.2	561.7	561.8
Bk2-6	Strain Ratio	1.18	1.19	1.17
Bk2-7	Elongation (%)	17.89	17.67	17.85
3	**Dacryodes edulis (steel bar coated specimen)**			
Bk3-1	Failure load (KN)	78.24	77.90	78.52
Bk3-2	Midspan deflection (mm)	6.48	7.18	6.53
Bk3-3	Bar diameter (mm)	16	16	16
Bk3-4	Yield Strength, fy (MPa)	460	460	460
Bk3-5	Tensile Strength, fu (MPa)	631.0	630.4	630.9
Bk3-6	Strain Ratio	1.31	1.31	1.32
Bk3-7	Elongation (%)	26.48	26.37	26.29

Table 3: Physiochemical Analysis of African Pear – UBE (Dacryodes Edulis) [15]

S/No.	Parameter	Test Method	Result	Standard
1	Potassium (%)	APHA 3111	0.008	0.10
2	Magnesium (%)	APHA 3111	0.04	0.10
3	Calcium (%)	APHA 3111	60.14	70.0
4	Phosphate (%)	APHA 3111	0.017	0.50
5	Manganese (%)	APHA 3111	0.05	0.50
6	Sulphate (%)	APHA 3111	0.030	1.00
7	Aluminium (%)	APHA 3111	0.030	1.00
8	Acidity number (KOH/g)	APHA 3111	0.019	0.05
9	Lead (%)	APHA 3111	0.015	0.05
10	Copper (%)	APHA 3111	0.055	0.50
11	Arsenic (%)	APHA 3111	0.017	0.10
12	Ash content (%)	APHA 3111	1.19	2.0 max
13	Moisture content (%)	APHA 3111	28.60	30 max
14	Density (kg/m^3)	APHA 3111	2.35	1.0 – 2.5
15	Iron	APHA 3111	0.206	0.5

3.1 Corroded beam members:

When compared to the non-corroded beam members, the flexural strength failure load decreases by 23%, the mid-span deflection increased by 40%, while the elongation decreased by 32%.

3.2 Dacryodes edulis coated beam members:

When compared to the corroded beam members, there was a 29% increase in the flexural strength failure load, 26% decrease in the mid-span deflection and a 48% increase in the elongation for the daceryodes edulis coated beam members.

3.3 Non-corroded beam members:

The non-corroded beam members served as the control. The percentage increase or decrease of the parameters mentioned above was based on the control values.

3.4 Chemical Analysis of the Resin (Dacryodes edulis- AFRICAN PEAR –UBE)

Table 3 shows the physiochemical analysis of the dacryodes edulis – (African pear–UBE). The components probably responsible for the corrosion inhibition properties are: Calcium and moisture. This is a result of the formation of Calcium Hydroxide Ca(OH)3, by the calcium (60%) and water (28.60%) in the dacryodes edulis. Calcium Hydroxide is a white powder or colourless crystal chemical compound that is formed by reacting lime and water. Calcium hydroxide can be used as a protective coating substance to prevent surface corrosion on some metals (https://www.corrosionpedia.com) [17].

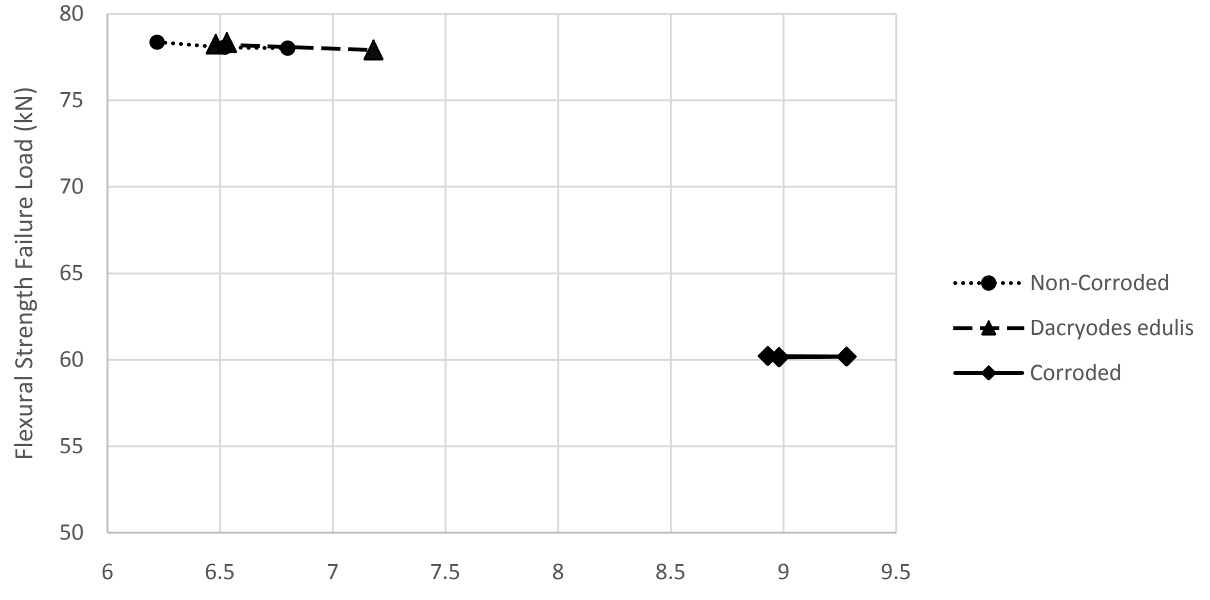

Fig 1.0 - Mid-span deflection (mm)

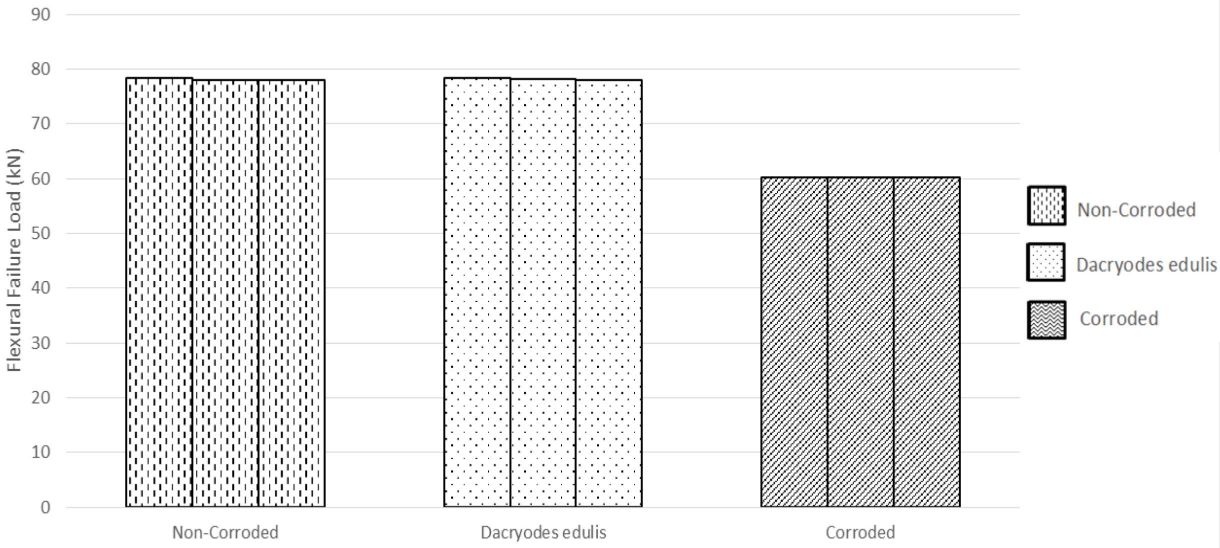

Fig 2. Bar Chart of Flexural Failure Load

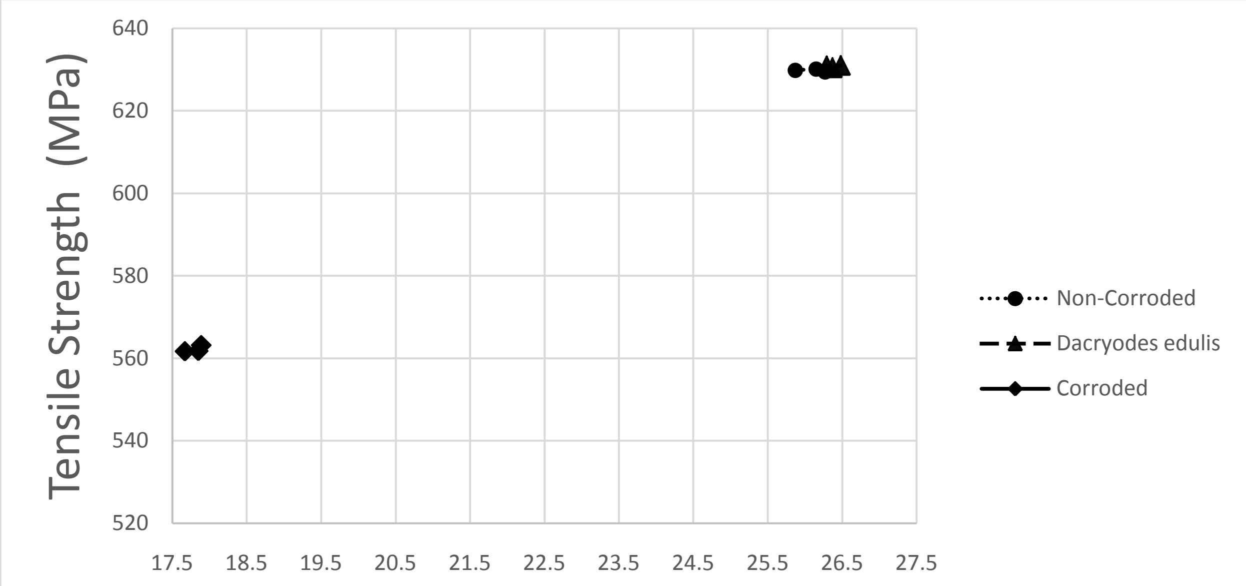

Fig 3.0 Elongation %

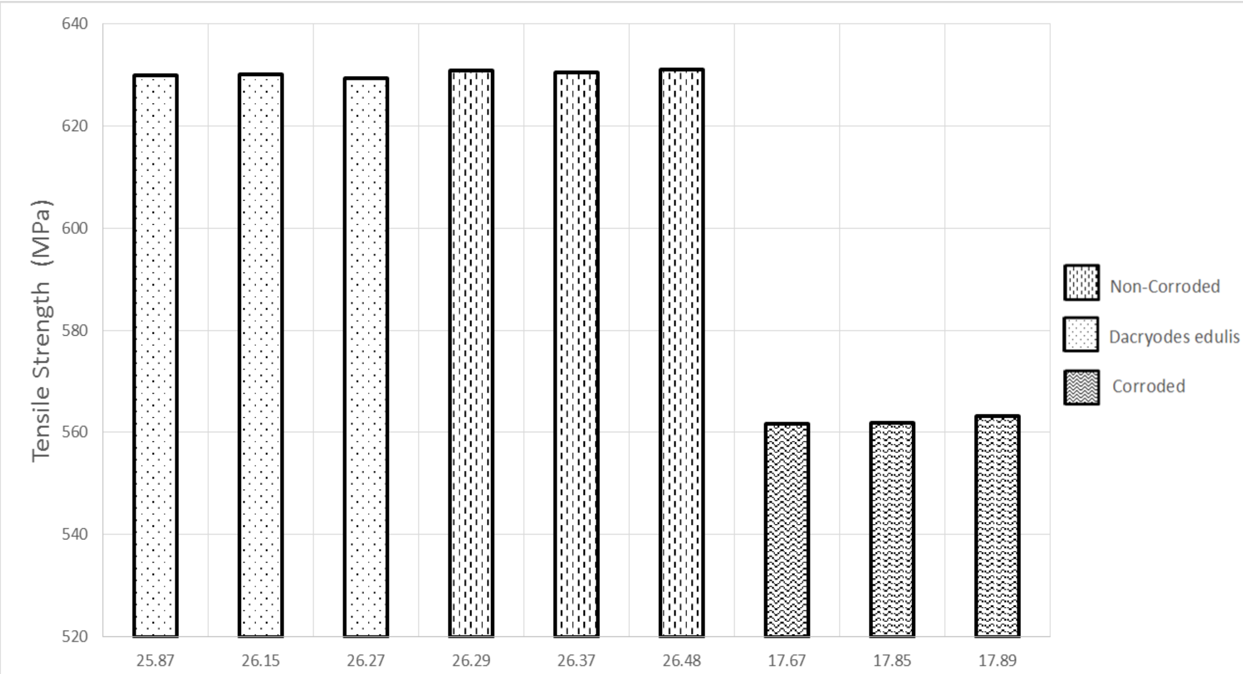

Fig 4. Elongation %

4.0 Conclusions

The following conclusions were drawn from the experimental investigations presented in Tables 1, 2 and 3 and figures 1 – 4.

i. Corroded beam shows higher deflection than an non-corroded and coated ones as a result of the degradation in the flexural stiffness due to corrosion that increases with increasing exposure to a corrosive medium.

ii. Non-corroded and dacryodes edulis coated steel members exhibited higher flexural strength failure loads, had lower mid-span deflection and elongation when compared to the corroded steel members. There was no significance difference between the values for the non-corroded and the dacryodes edulis coated members.

iii. From (ii) above and Table 3, dacryodes edulis can act as a corrosion inhibitor. The material in Table 3 .

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

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

vi. 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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