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EFFECT OF CORROSION ON THE MECHANICAL PROPERTIES OF STEEL REINFORCEMENT

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ABSTRACT

Reinforced concrete structures in coastal areas under goes severe damage due to corrosion of reinforcement during its design life. The gradual degradation of the structural integrity due to corrosion results in considerable financial burden. Such structure when subjected to seismic action undergoes severe damage. Under the action of seismic loads, the reinforcement bars are subjected to tension and compression. Hence in present study, the effect of corrosion on the mechanical properties of reinforcement is studied. In compression test there is no significant reduction in average ultimate stress and average ultimate load for corrosion level of 5% for specimens with L/D ratio of 10 and 15. The reduction in average ultimate load is not proportional to the level of corrosion. It is also observed that the percentage decrease in average ultimate load is higher than the level of corrosion. It could be noted that the average ultimate stress decreases slightly lesser than the level of corrosion. The effect of L/D ratio affects both average ultimate load and ultimate stress significantly. In cyclic test the maximum load decreases slightly lesser than the level of corrosion. It is also observed that the percentage decrease in maximum stress in cyclic test is lesser than the level of corrosion in tension and it is higher than the level of corrosion in compression. A huge reduction in both mean load and mean stress beyond 0.5% of strain in compression is observed in cyclic test.

Key Words: Reinforced concrete, Corrosion, Severe damage, Ultimate load, Ultimate stress

INTRODUCTION

Reinforced concrete structures are durable and strong, hence are versatile. However, reinforced concrete exhibit structural distress due to inadequate design, substandard construction practice and environmental effects or a combination of above factors. Corrosion of reinforcing bars is the most common environmental effect that results in premature deterioration of reinforced concrete structures. The diameter of the steel bar diminishes causing reduction in cross section and thereby affecting the load carrying capacity of member. Corrosion reduces the ductility of the steel and energy absorption capacity of steel significantly (Du et al. (2005), Almusallam (2001), Palsson and Mirza (2002). It is well known reinforced concrete structures in coastal areas; under goes severe damage due to corrosion of reinforcement during its design life. The behavior of corroded rebar under tension is well understood. Hence in present study, the effect of corrosion on the mechanical properties of reinforcement is studied.

METHODOLOGY

Corrosion of steel in concrete is a slow process. Due to protective nature of concrete, it takes reasonably a long time for initiation and progress of reinforcement corrosion even in the case of severe exposure conditions which is too long for laboratory studies. It is difficult to achieve a significant degree of corrosion in reinforcement within a limited duration (Shamsad Ahmad, 2009). Thus for laboratory studies, the corrosion is accelerated. Acceleration corrosion process is a technique based on the fact that corrosion process is activated by Chloride ions and accelerated by electrical polarization of the reinforcement steel. For present study the rebars are subjected to three different levels of corrosion viz, 5%, 10% and 20% of weight loss over the gauge length and also the L/D ratio of the specimen are varied as 5, 10 and 15. Three specimens are tested for each case hence totally 36 specimens of 8mm diameter are tested in compression. The details of test specimens are given in table I

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ACCELERATED CORROSION PROCEDURE

Accelerated corrosion is carried out by connecting reinforcement to the positive terminal (Anode) of the DC pack and the stainless steel plates to the negative terminal (Cathode) of the DC pack of 32V and immersing reinforcement rod in 3.5% NaCl solution. The time taken for inducing particular level of corrosion is estimated based on Faraday's law of electrolysis and the typical accelerated corrosion test setup is shown in figure 1.

Typical calculation to estimate time required for corrosion:

Current density = 800μA/cm^2

$$I = \frac{\text{Current density} \times \pi \times d \times L \times 10^{-6}}{100} \quad \text{(I)}$$

Where,

I = Current to be supplied (A)
L = Length of the specimen (mm)
d = Diameter of the specimen (mm)

Time required for inducing particular level of corrosion is estimated based on Faraday's law as shown below:

$$T = \frac{\Delta W \times Z \times F}{a \times I} \quad \text{(II)}$$

Where,
T = Time (sec)
Z = Ionic charge (+2 for steel)
F = Faraday's constant (96500 amp-sec)
a = Atomic weight of metal (56g for Fe)

EXPERIMENTAL PROGRAMME

COMPRESSION TEST ON REBARS

The compression tests are carried out on Compression Testing machine of 2000kN capacity in load control mode. The steel specimen are mounted between the grips and subjected to monotonic increase in loading till failure. The initial lengths between the grips are noted and displacements of the ram during the test are measured using LVDT. The applied loads are monitored using load cell. Figure 2 gives the typical test setup. The load data from load cell and LVDT are acquired using data logger (MGC+) at the sampling rate of 50Hz. The load is increased monotonically till the failure. Totally 36 numbers of specimens are tested under compression on 8mm diameter by varying L/D ratio and different level of corrosion. Three L/D ratios are chosen for study are 5, 10 and 15 and are subjected to three levels of corrosion (5%, 10% and 20%). It is also observed that with increase in level of corrosion the buckling load decreases. It is observed that for L/D ratio of 15 the influence of corrosion decreases the load carrying capacity drastically. Hence, cyclic tests are carried out on failure pattern of specimen with L/D ratio 15. 16mm diameter bars with L/D ratio of 15 and subjected to three levels of corrosion namely 5%, 10% and 20%.

CYCLIC TEST ON REBARS

A total of 12 specimens are subjected to reverse cyclic loading for L/D ratio of 15 with three different levels of corrosion. Cyclic test carried out on servo controlled Universal Testing machine of capacity 250kN with a grip length of 80mm as shown in figure 3. The displacement and load are recorded using data acquisition system (MGC+). The specimens are subjected to reverse cyclic loading in displacement control mode. The displacement histories are calculated as percentage strain shown in figure 4. Three cycles of each displacement are applied. All the specimens failed at the centre except one specimen with 20% of corrosion.

RESULTS

OBSERVED COMPRESSION TEST RESULTS

Average ultimate stress and load observed in compression tests are given in Table II. The ultimate stresses reported are calculated as load divided by reduced area due to corrosion. The reduced area is obtained by calculating diameter of the rebar at ten locations over the gauge length by digital vernier caliper are shown in Table III. The mean of ten readings are recorded as the diameter of the reduced area due to corrosion. Variation in ultimate stress and ultimate load with respect to different L/D ratio for each level of corrosion is shown in figure 5 to 10.

OBSERVED CYLIC LOAD–DISPLACEMENT RESPONSE

The mean load- displacement graphs observed from cyclic tests are shown in following figure 11 to figure 14.

OBSERVED CYCLIC STRESS-STRAIN RESPONSE

The mean stress verses strain observed from the cyclic tests are shown in following figure.15 to figure.18.

CONCLUSIONS

FROM COMPRESSION TEST ON REBAR`

- It is observed that there is no signification reduction in average ultimate stress and average ultimate load for corrosion level 5% for specimens with L/D ratio of 10 and 15.
- It could be observed that reduction in average ultimate load is not proportional to the level of corrosion. It is also observed that the percentage decrease in average

ultimate load is higher than the level of corrosion.

- It could be noted that the average ultimate stress decreases slightly lesser than the level of corrosion. For example, for 20% level of corrosion the average ultimate stress is reduced by 9.1% and 9% for L/D ratio of 10 and 15.
- The effect of L/D ratio affects both average ultimate load and ultimate stress significantly.

FROM REVERSE CYCLIC TEST ON REBAR

- It could be noted that the maximum load decreases slightly lesser than the level of corrosion. It is also observed that the percentage decrease in maximum stress is lesser than the level of corrosion in tension and it is higher than the level of corrosion in compression.
- It is observed that there huge reduction in both mean load and mean stress beyond 0.5% of strain in compression.

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LISTS OF SYMBOLS & ABBREVIATIONS

A	Amphere
As	Amphere-sec
⁰C	Degree Celsius
cm^2	Square centimetre
DC	Direct current
⁰F	Degree Fahrenheit
G	Gram
Hr	Hours
Kn	Kilonewton
L/D	Length to Depth ratio
LVDT	Linear Variable Differential Transducer
M	Metre
m^3	Cubic metre
mA	Milli amphere
Min	Minutes
Ml	Milli litre
Mm	Milli metre
mV	Milli volt
Mpa	Megapascsal
MJ	Mega joule
S	Seconds
V	Voltage

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Table I: Gauge Length Details of Specimen for Different L/D Ratios

L/D ratio	Diameter of bar (mm)	Level of corrosion (%)	Gauge length (mm)
5	8	0, 5, 10 & 20	40
10	8	0, 5, 10 & 20	80
15	8	0, 5, 10 & 20	120

Table II: Average Ultimate Load and Stress

Specimen	Ultimate Stress (Mpa)	Ultimate load (kN)
D8C0L5	559.84	27.22
D8C5L5	537.85	24.70
D8C10L5	521.94	23.23
D8C20L5	477.82	18.85
D8C0L10	472.84	22.99
D8C5L10	474.95	22.22
D8C10L10	449.14	20.04
D8C20L10	429.57	16.28
D8C0L15	438.49	21.32
D8C5L15	422.14	21.20
D8C10L15	415.46	18.84
D8C20L15	398.79	12.94

Table III: Reduced Mean Diameter Measured after Corrosion

Specimen	Reduced mean diameter (mm)
D8C5L5	7.65
D8C10L5	7.53
D8C20L5	7.09
D8C5L10	7.72
D8C10L10	7.54
D8C20L10	6.95
D8C5L15	7.74
D8C10L15	7.6
D8C20L15	6.43

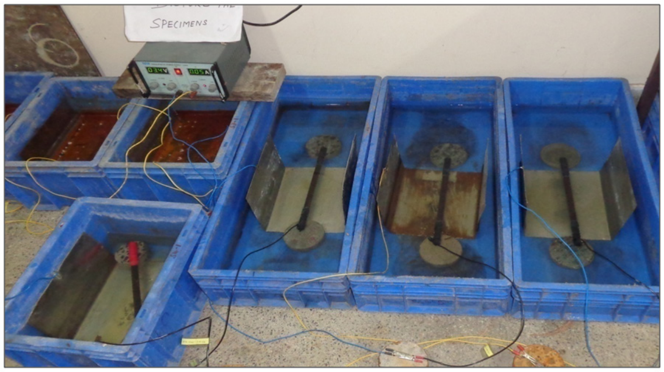

Figure 1: Typical accelerated corrosion test setup.

Figure 2: Test setup for compression testing of reinforcement.

Figure 3: Cyclic test setup.

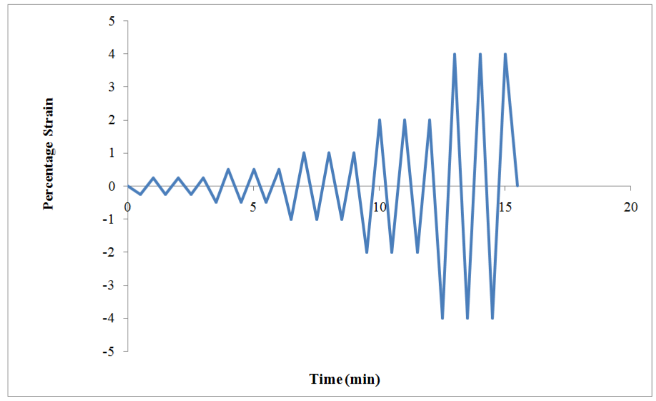

Figure 4: Load History in terms of Strain (%).

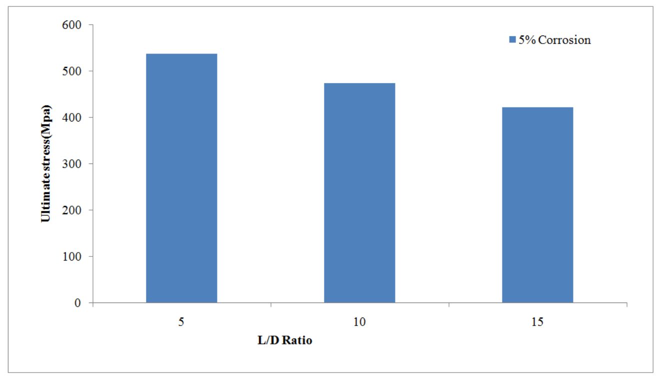

Figure 5: Variation of ultimate stress for different L/D ratio for 5% corrosion.

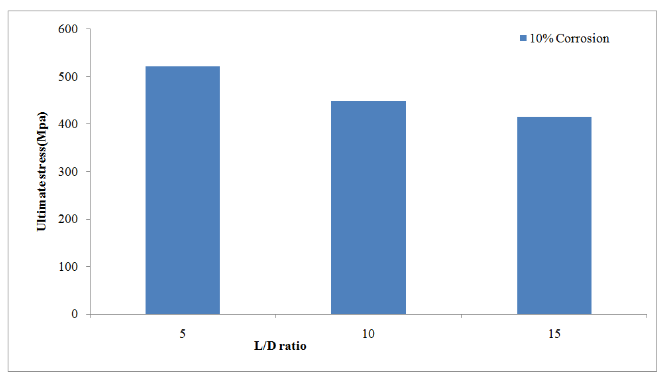

Figure 6: Variation of ultimate stress for different L/D ratio for 10% corrosion.

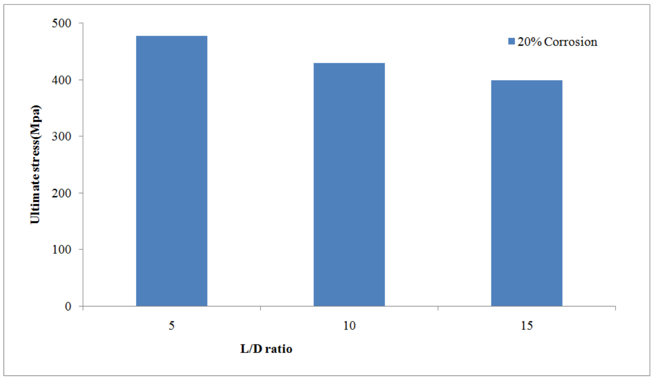

Figure 7: Variation of ultimate stress for different L/D ratio for 20% corrosion.

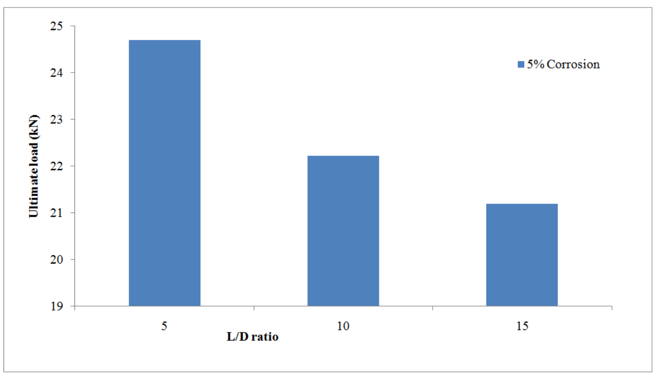

Figure 8: Variation of ultimate load for different L/D ratio for 5% corrosion.

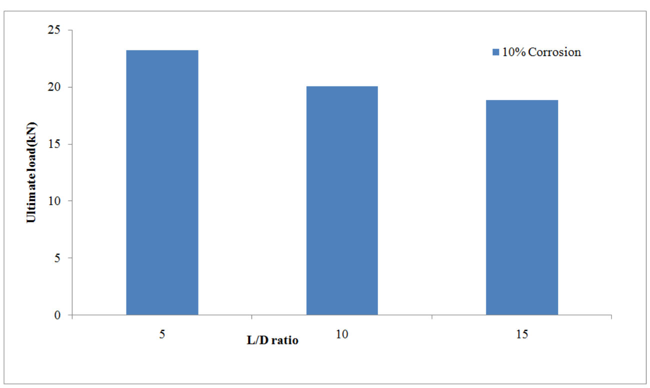

Figure 9: Variation of ultimate load for different L/D ratio for 10% corrosion.

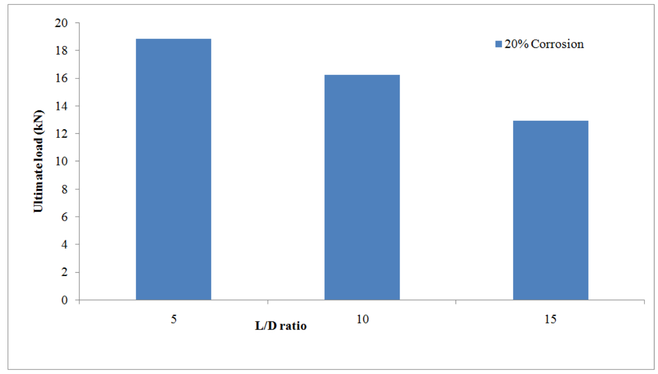

Figure 10: Variation of ultimate load for different L/D ratio for 20% corrosion.

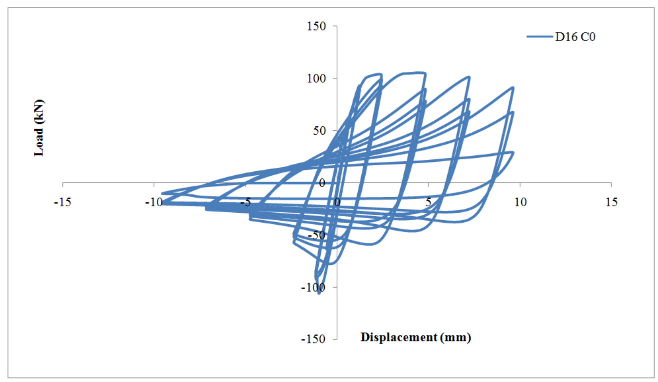

Figure 11: Mean Load – Displacement graph for control specimens.

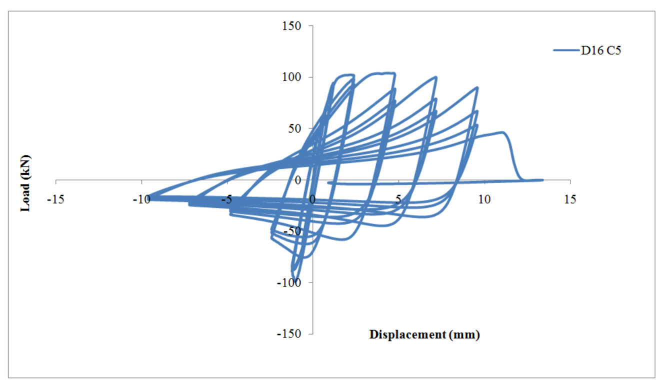

Figure 12: Mean Load – Displacement graph for 5% corroded specimens.

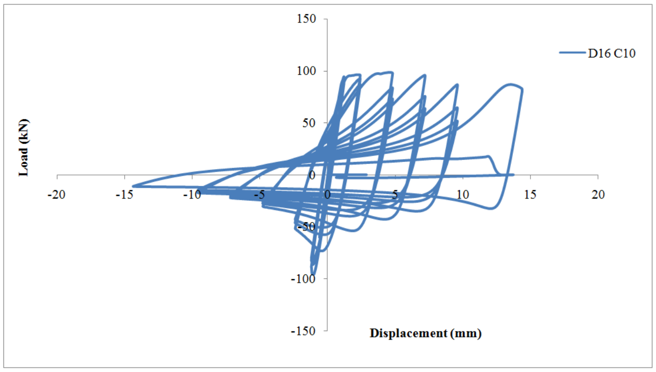

Figure 13: Mean Load – Displacement graph for 10% corroded specimens.

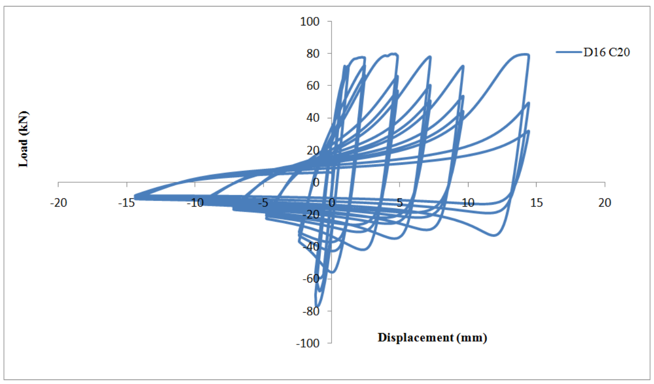

Figure 14: Mean Load – Displacement graph for 20% corroded specimens.

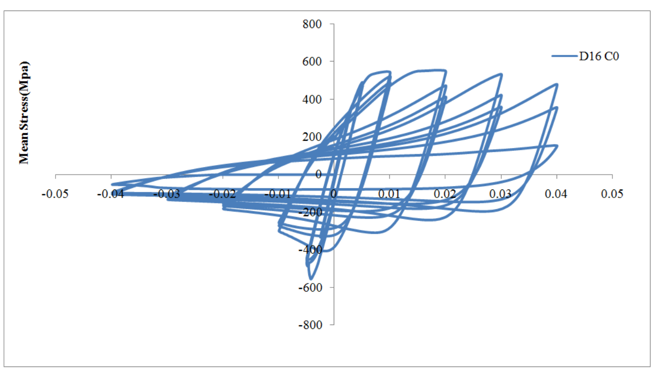

Figure 15: Mean stress-strain graph for control specimens.

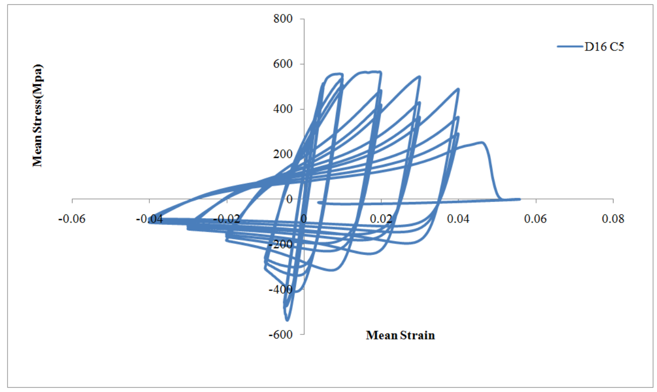

Figure 16: Mean stress-strain graph for 5% corroded specimens.

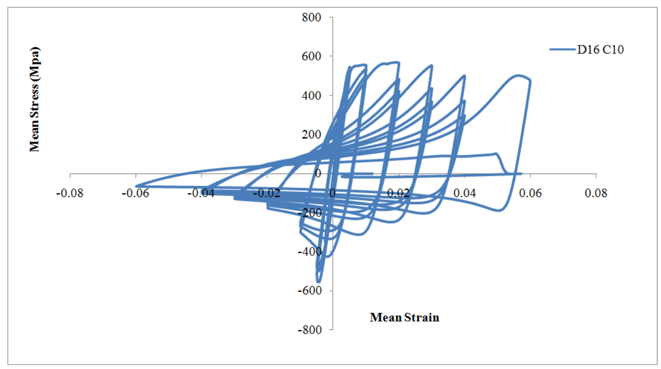

Figure 17: Mean stress-strain graph for 10% corroded specimens.

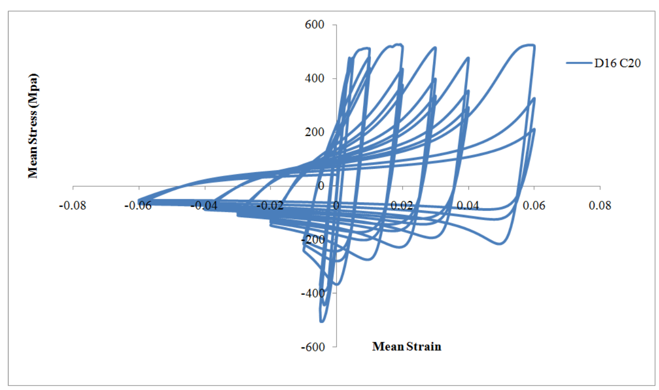

Figure 18: Mean stress-strain graph for 20% corroded specimens.