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Effect of Preloading and Nano-Silica on Structural Behavior of Corroded R.C. Beams

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Abstract: *Reinforced concrete structures are considered as permeant structures that can be used for a long time. But, one of the most issues has been discussed in construction community was corrosion of embedded steel bars. Corrosion has a negative significantly effect on the behavior of reinforced concrete structures where decrease bar cross section, formats massive products, reduces bond between concrete and steel bars and also, reduced load capacities. To simulate corrosion under loading condition, the specimens were subjected to preloading before corrosion process. Also, addition of nano-silica to concrete mixes with variable ratios was studied to show its effect on corrosion rate. 8 beams were divided into two groups (A and B) with preloading and unloading respectively. Then, all beams were corroded accelerable. 4 concrete mixes were designed. The experimental result included compressive strength of concrete, corrosion cracks pattern, steel mass loss and ultimate flexural load. Finally, it was noticed that preloading had negative effect in steel mass loss, ultimate load, and increased cracks. On contrary, addition of nano-silica improves the structural properties of corroded beams*

Keywords: *Corrosion; Nano-Silica; preloading; Beams retrofitting.*

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I. Introduction

One of the most perfect construction materials was used around the world is Reinforced concrete (R.C). owing to, the good compatibility between steel and concrete where acts as the same unit and low costs of used materials. Consequently, reinforced concrete structures are considered as permeant structures that can be used for a long time. Although, the concrete gives a good protection for embedded steel bars against some attacked materials along service duration of structure. One of the attacked materials is chlorides which causes corrosion. Corrosion is considered one of the most issues has been discussed in construction community [**1-3**]. Steel corrosion is regarded as durability problems in serviceability limit state. Moreover, corrosion has a negative significantly effect on the behavior of reinforced concrete structures. Effects can be summarized to **I) physically**, corrosion leads to decrease of cross section of steel bars and format massive products than the original volume of steel bars [**4**]. **II) mechanically**, due to loss of cross section, mechanical properties of steel bars decrease and load carrying capacities of elements degrade [**5-8**]. Also, massive products causing reducing on bond action between steel and concrete hence, deflection increased and structural stiffness decreases along service life [**9-10**].

Many researches had been done to evaluate the behavior of corroded reinforced concrete beams where beams were corroded firstly and tested up to failure. Whilst, steel corrosion process takes place during the usage of structure. Therefore, many researchers experimented the combined relationship preloading and corrosion rate along life of structure.

Uomoto and Misra [**11**] studied the behavior of R.C. beams without preloading and with preloading to induce flexural cracks. The beams were corroded by adding different concentration of sodium chloride to mixing water and then electrical current was impressed to beams. Tests illustrated bearing capacities of corroded beams without preloading were more than corroded beams with preloading. **Huang and Yang** [**12**] studied relationship between corrosion level of steel bars in R.C. beams with and without preloading and their loads capacities. beams were constructed with different concrete mixes where they used two different water to cement ratio (w/c) with middle flexural cracks and without. The results showed that the flexural capacity of beams was reduced as the corrosion was increased in specimens. also, maximum level of corrosion was founded in preloaded beams due to easy access of chloride ions to reinforcement. **Yoon et al,** [**13**] performed variable tests on reinforced concrete beams. The variation was in loading conditions, first group of beams were conducted to sustained load during corrosion process, second group were conducted to preloading before and then corroded and last group were not conducted to preloading or sustained loads during corrosion. All beams were tested and they observed that beams with sustained load had the higher mass loss in steel than beams were subjected to preloading and finally, corroded beams with no sustained load or no preloading had lowest mass loss and highest loading capacities.

As mentioned before, preloading effect negatively on load carrying of beams and also, increase of steel mass loss. On country, using of nano-silica can improve the properties of concrete mix and permeability of concrete. **Prasath et al,** [**14**] tested the mechanical properties designed mixes such as, durability, compressive strength and flexural strength. The mixes were varied in content of silica-fume (5%, 7.5%, 10%, and 12.5%) and content of nano-silica (1%, 2%, 3%, and 4%) as cement replacement. It was found the mix with 7.5% silica-fume and 2% nano-silica has perfect properties. Finally, R.C. specimens were fabricated and corroded. Nono concrete specimens had the lowest mass loss of steel. **Zapata et al,** [**15**] examined the mixing of nano-silica with micro-silica. They founded an improvement in mechanical properties of concrete where, highest strength, lowest water absorption and chloride penetration were achieved in micro/nano concrete.

Objectives

The objectives of this study are to evaluate the influence of adding nano-silica on corrosion rate. Also, evaluate of preloading on the behavior of R.C. beams containing nano-silica. Finally, verification of load carry capacities of beams experimentally and analytically.

Experimental Program

8-R.C. beams were divided into two groups (A and B). each group consists of 4 beams. Beams in group A were subjected to preloading whilst, beams in group B were not subjected to any loads. 4-beams in each group were casted with variable ratios from nano-silica. Beams in 2-groups were accelerated corroded by the same technique. **Table (1)** shows summary to experimental program.

Table (1): summary of experimental program

Group	Specimens	Preloading	Silica-Fume (% of cement)	Nano-Silica (% of cement)	Design Mass loss (%)
A	B1	Preloading about 65% ultimate load	0	0	7
	B3		8	0	7
	B5		8	1	7
	B7		8	1.5	7
B	B2	No Preloading	0	0	7
	B4		8	0	7
	B6		8	1	7
	B8		8	1.5	7

Materials

Crushed graded dolomite from local resources was used as a course aggregate. Maz size of aggregate was 10 mm and the specific gravity was 2.66. for fine aggregate, natural sand was used, which was cleaned from impurities and chlorides. the specific gravity was 2.7. Cement was grade 52 and locally nano-silica, which is considered highly pozzolanic material, were used. Nano-silica has a very verity in sizes but, all size under 100 nm as shown in **figure (1)**. The micro-silica (silica-fume) and superplasticizer (Glenium C35) were. Two 12 mm diameter deformed bars were used as bottom steel. 12 mm bars were high tensile steel with yield stress about 617 MPa and ultimate stress 730 Mpa. Also, two 6 mm diameter plain bars were used as top steel and stirrups. 6 mm bars were high tensile steel with yield stress about 254 MPa and ultimate stress 365 Mpa.

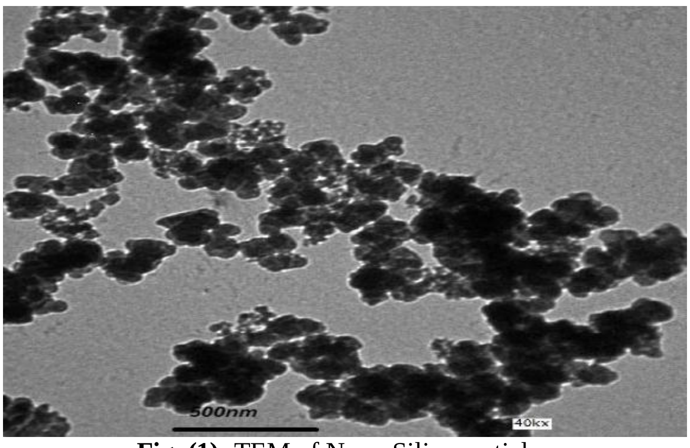

Fig. (1): TEM of Nano-Silica particles

Specimens details

The details of specimens were shown in **figure (2)**. Each specimen was 1510 mm long with cross section 110 width and 210 thickness. Each beam has Two 12 mm diameter deformed bars which were placed longitudinally in tension zone. Also, two 6 mm diameter plain bars which were placed longitudinally in compression zone. 6 mm diameter stirrups were used as shear reinforcement with 100 mm spacing. To make sure the corrosion will happen in flexural bars, protection of compression bars and stirrups was done by plastic tap which was wrapped around the corners of stirrups at touching zone between stirrups, compression steel, and flexural steel. So, the corrosion was restricted to tensile steel only. Flexural steel bars were bent at the ends of beam and extended approximately 50 mm above top surface of specimen.

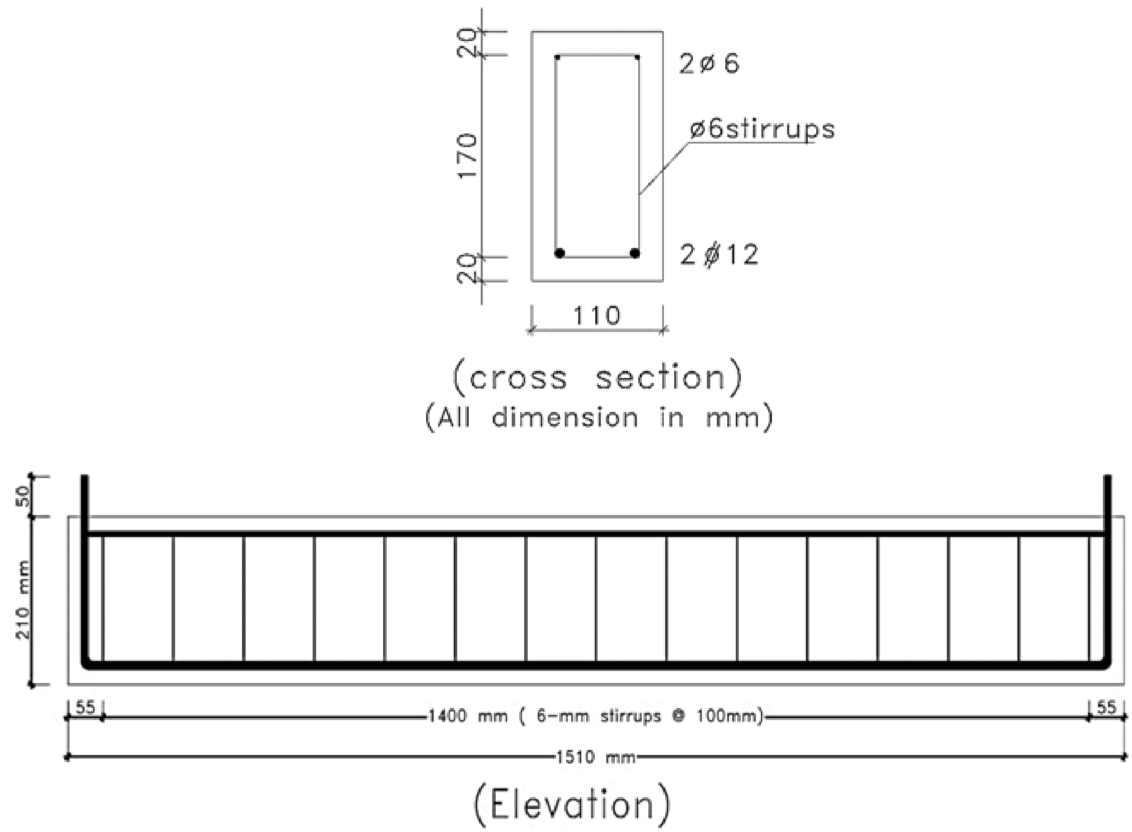

Fig. (2): Details of tested specimens

Concrete mixes

4 concrete mixes were used for casting for all specimens where proportions of concrete mixes were given in **table (2)**. Each concrete mix was used for casting two specimens, one with preloading and the other without any loading. The concrete mix (**CO**) was made by using CEM I 52.5 without any addition while, three others three concrete mixes were made by adding portions of micro-silica and nano-silica as replacement of cement. 8% micro-silica concrete mix (**MS8**) was formed by adding micro-silica (8 % from cement weight). Also, for 8 % micro-silica + 1 % nano-silica concrete mix (**MNS81**), micro-silica and nano-silica were added by 8 % and 1 % from cement weight respectively. 8 % micro-silica + 1.5 % nano-silica concrete mix (**MNS81.5**) used micro-silica and nano-silica, which were added by 8% and 1.5 % from cement weight respectively. All concrete mixes had constant water to cementitious material (W/C) ratio of 0.43 with total cementitious material content of 400 kg/m^3.

Table (2): Concrete Mixes proportions (Kg/m^3)

Concrete Mix Notation	Coarse Aggregate	Fine Aggregate	Cement	Water	S. P	Micro Silica	Nano Silica
Co	1200	600	400	172	8	0	0
MS8	1200	600	368	172	8	32	0
MNS81	1200	600	364	172	8	32	4
MNS81.5	1200	600	362	172	8	32	6

preloading technique and accelerated corrosion system

preloading technique: After casting and curing of specimens, beams in group A were subjected to preloading about 65 % of ultimate load as service load. The load was applied at central point of beams as shown in **figure (3)**. The applied load was remained affecting on the beam about 10 minutes.

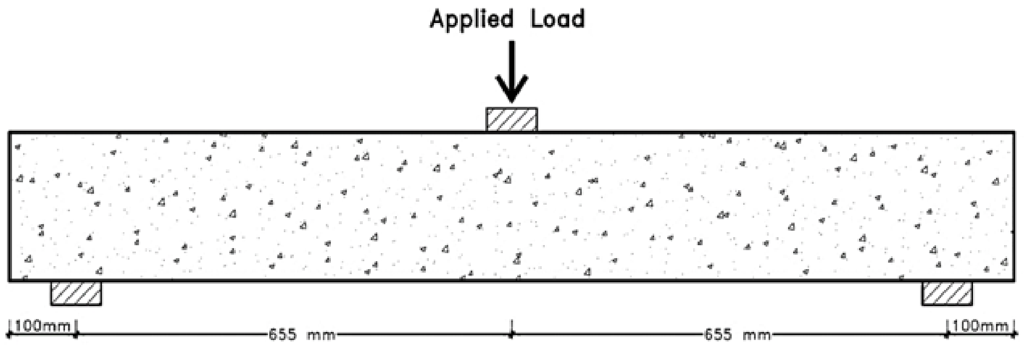

Fig. (3): Preloading technique

Accelerated corrosion: To speed up the corrosion process, an externally applied electrical current and cycles of wetting and drying with NaCl solution. The corrosion cell consists of **I) Anode** which was represented by steel bars, **II) Cathode** which was represented by steel wire mech. Steel wire mech was wrapped around beam body, and **III) Electrolyte solution** was formed by 3.5 % NaCl solution. The anode was connected to the positive terminal of power supply. On the other hand, the cathode was connected to negative terminal. Gunny sack piece was placed between beam body and steel wire mesh. The NaCl solution had been sprayed on the beams two times a day (one at around 7.00 AM and other around 2.00 PM). **Figure (4)** gives a clear show for corrosion cell contents.

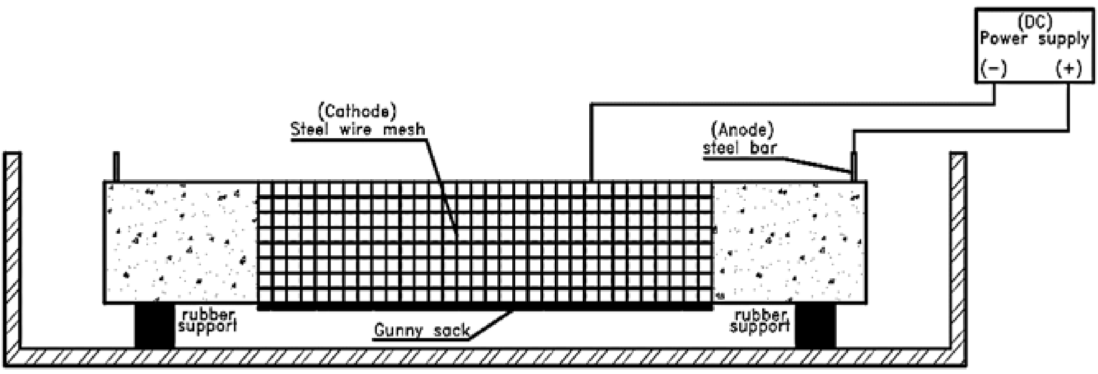

Fig (4).: Accelerated corrosion system

Test setup

All specimens were tested in testing frame of reinforced concrete research laboratory of faculty of engineering, Banha University as shown in **Figure (5)**. The load was applied by hydraulic jack which was connected to braced frame. To measure the acting load, load cell was connected to jack. The load was acted at central point of beam. The supports were placed at 100 mm from each end of beam. 3 LVDT were used to deformation accompanied to load as shown in **Figure (6)**.

Fig. (5): Framed used in testing

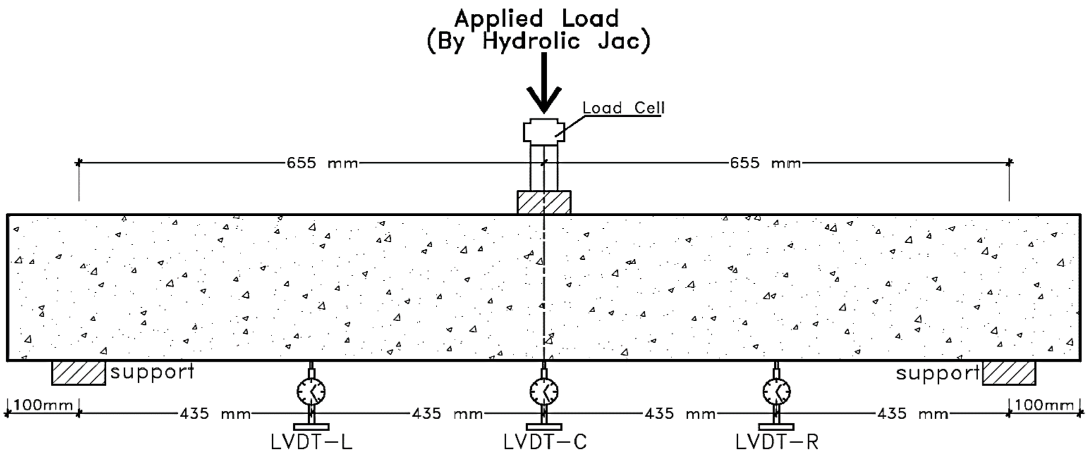

Fig. (6): Test setup

Experimental results and discussion

Effect of nano-silica on compressive strength

12 cubes (150 x 150) mm were casted from the same concrete mixes of beams. **Figure (7)** shows the compressive strength of 4 concrete mixes after 28 days. Control mix (CO) had the lowest compressive strength of 50.7 MPa, whilst MS8, MNS81 and MNS81.5 had compressive strength 54PMPa, 62.6 and 58.1 respectively. The increase of compressive strength of MS8, MNS81 and MNS81.5 was 107%, 124% and 115% respectively.

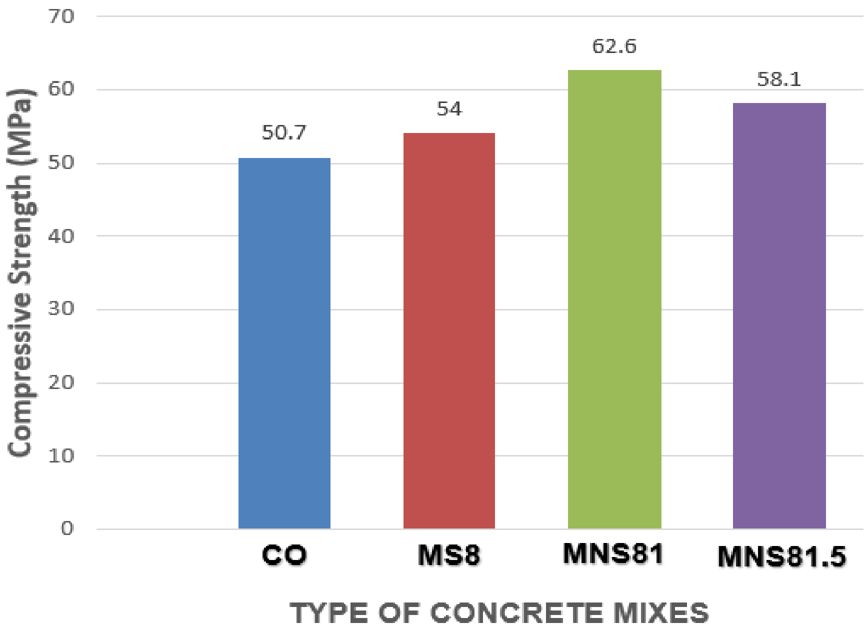

Fig. (7): Compressive strength of concrete mixes used

Corrosion cracks pattern

Due to preloading, numerous of transversal cracks were happened. During the steel corrosion, products of corrosion were effused from the pre-cracks. With increasing of corrosion rate, longitudinal cracks along steel bars were formed. As shown in **Figure (8),** all beams with preloading exhibited a large number of longitudinal cracks at the bottom and sides. On the other side, beams without any loading exhibited small number of longitudinal cracks.

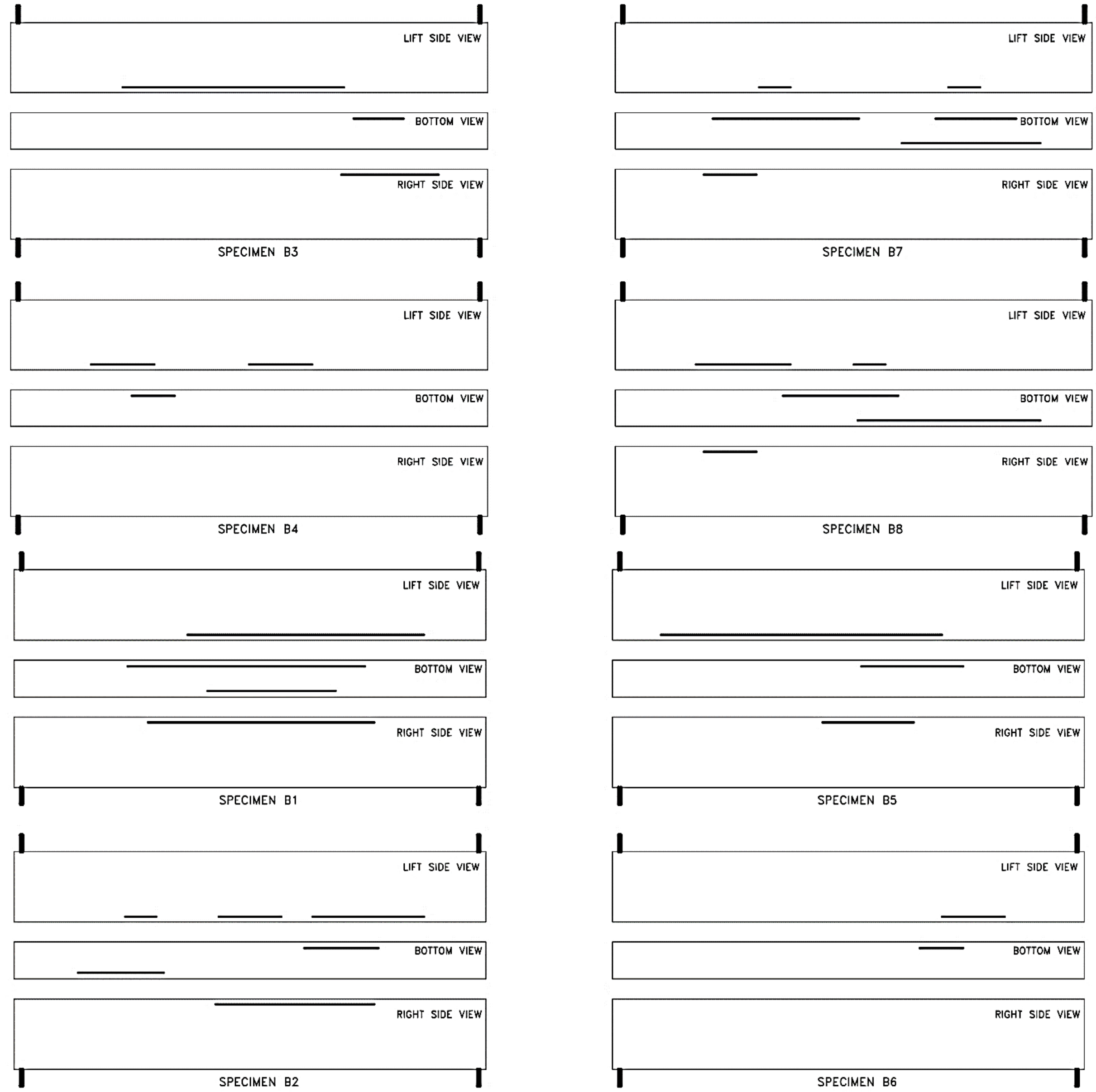

Fig. (8): Corrosion cracks pattern

Steel mass loss

After end of corrosion process and also after experimental tests. The steel bars were extracted from beams then cleaned from rust. The steel mass loss was calculated according to the following equation.

$$\%\ \boldsymbol{of\ steel\ mass\ loss} = \frac{(\textbf{Initial Weight} - \textbf{Final Weight})}{\textbf{Initial Weight}}\ \boldsymbol{x\ 100}$$

From results, we had two factors affecting on steel mass loss: **I**) Influence of nano-silica addition and **II)** Influence of preloading.

For loaded and unloaded beams, the control mix (CO) had highest mass loss of steel, while concrete mixes MS8, MNS81 and MNS81.5 had lowest mass loss. As shown in **Figure (9),** the average percentage of mass loss of concrete mixes CO, MS8, MNS81 and MNS81.5 was 6.5, 5, 4.2 and 4.8 respectively.

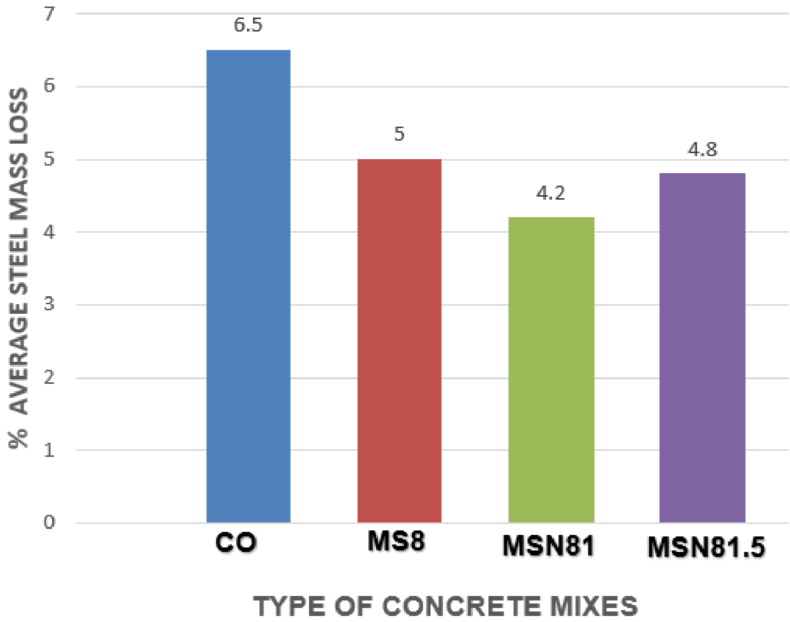

Fig. (9): Influence of Nano-Silica on mass loss

Preloading has negatively effect on steel bar cross section where increases the mass loss as shown in **Figure (10)**. 4 beams in group A which were corroded with preloading had average percentage of mass loss about 6.7, 5.1, 4.6 and 4.7 respectively, whilst 4 beams in group B which were not subjected to any load had average percentage of mass loss about 6, 4.9, 3.8 and 5 respectively.

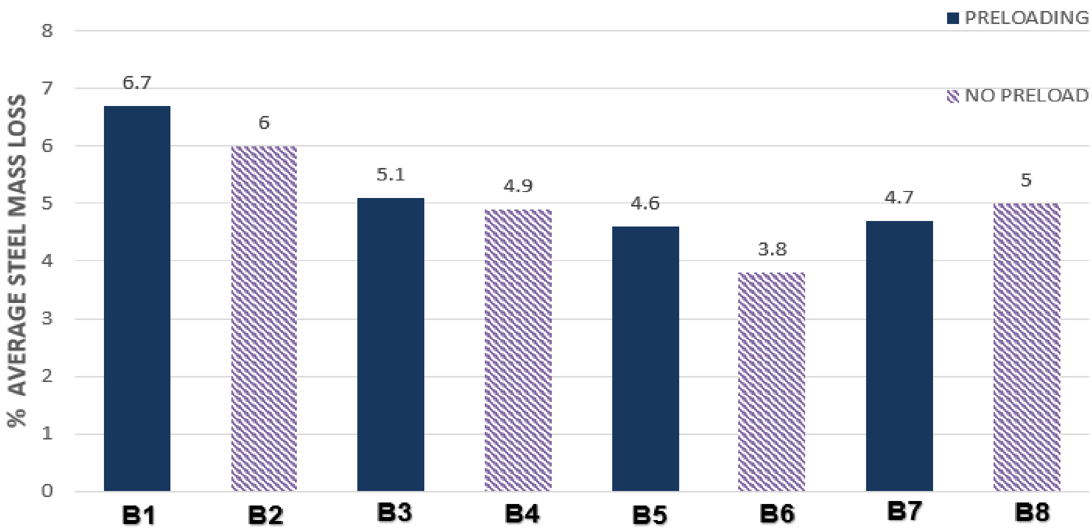

Fig. (10): Influence of preloading on mass loss

Ultimate flexural load

Relationship between load and displacement of every specimen was plotted. It was observed on load capacities of beams that preloading decrease load capacity of beam. On contrary, nano-silica addition increase load capacity of beam. For preloaded specimens B1, B3, B5 and B7 had ultimate load of 74.5 KN, 76.7 KN, 80.7 KN and 80.7 KN respectively as shown in **Figure (11)**. It was noticed that specimen B5 and B7 which had concrete mixes MNS81 and MNS81.5 respectively had max load. For unloaded specimens B2, B4, B6 and B8 had ultimate load of 74.9 KN, 77.6 KN, 82.7 KN and 77.4 KN respectively as shown in **Figure (12)**. It was noticed that specimen B6 which had concrete mixes MNS81 had max load.

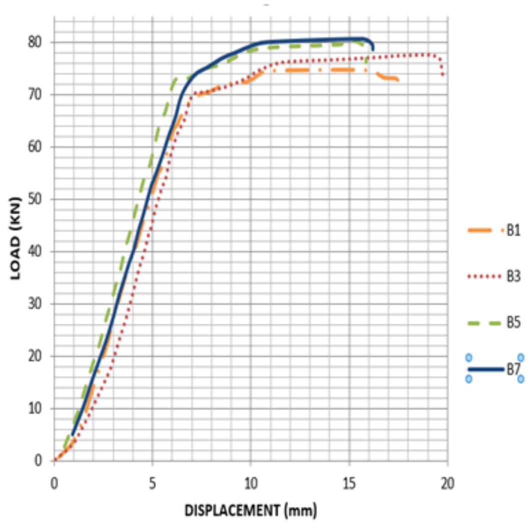

Fig. (11): Ultimate load for loaded beams

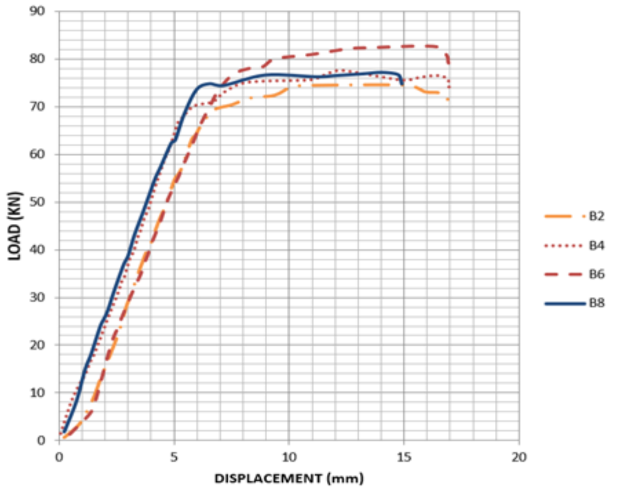

Fig. (12): Ultimate load for unloaded beams

II. Conclusions

Based on the investigation and experimental results described, a number of conclusions may be considered for addition of nano-silica and preloading effects. The findings are summarized below.

1. Addition of nano-silica improves the concrete quality and this reflected on compressive strength. The compressive strength was increased significantly when MNS81 was used. The increment was about 124%. Also, all concrete mixes with nano-silica were increased in compressive strength.
2. Preloading effect negatively on longitudinal crack, which increases the number of cracks. All preloaded beams exhibited large number of longitudinal cracks, whilst the unloaded beams exhibited small number of longitudinal cracks.
3. Beams which were contended nano-silica showed improvement in longitudinal cracks for beams with same category (preloaded or unloaded).
4. Preloading increases the steel mass loss where reduces the bar cross section. 4 beams in group A had average percentage of mass loss about 6.7, 5.1, 4.6 and 4.7 respectively, whilst 4 beams in group B had average percentage of mass loss about 6, 4.9, 3.8 and 5 respectively.
5. Addition of nano-silica improves steel mass loss. the average percentage of mass loss of concrete mixes CO, MS8, MNS81 and MNS81.5 was 6.5, 5, 4.2 and 4.8 respectively.
6. All specimens with addition to nano-silica (if preloaded or unloaded) exhibited maximum ultimate flexural load rather than concrete mix. Also, preloading decrease ultimate flexural load of beam. For preloaded specimens B1, B3, B5 and B7 had ultimate load of 74.5 kN, 76.7 kN, 80.7 kN and 80.7 kN respectively. For unloaded specimens B2, B4, B6 and B8 had ultimate load of 74.9 kN, 77.6 kN, 82.7 kN and 77.4 kN respectively.

References

[1]. Broomfield J (2002) Corrosion of steel in concrete: understanding, investigation and repair, 2nd Ed. Taylor & Francis, Abingdon, United Kingdom.
[2]. Miyagawa, T. (1991). "Durability design and repair of concrete structures: chloride corrosion of reinforcing steel and alkali aggregate reaction", Magazine of Concrete Research, Vol. 43, No. 156, pp. 155–170.
[3]. Bentur, A., Diamond, S. and Berke, N.S. (1997). Steel Corrosion in Concrete: Fundamentals and Civil Engineering Practice, E&FN Spon.
[4]. Almusallam, A.A., Al-Gahtani, A.S. & Aziz, A.R., 1996. Effect of reinforcement corrosion on bond strength. Construction and Building Materials, 10(2), pp.123–129.
[5]. El Maaddawy, T.; Soudki, K.; Topper, T. Long-Term Performance of Corrosion-Damaged Reinforced Concrete Beams. ACI Struct. J. 2005, 102, 649–656.
[6]. Jin Weiliang, Xia Jin, Jiang Aoyu, Wang Hailong. (2009) Flexural capacity of corrosion damaged RC beams. China Civil Engineering Journal, 42(11): 64-70.
[7]. Francois, R.; Khan, I.; Dang, V. Impact of corrosion on mechanical properties of steel embedded in 27-year-old corroded reinforced concrete beams. Mater. Struct. 2012, 46, 899–910.
[8]. Goitseone Malumbela, Mark Alexander and Pilate Moyo. (2010) Variation of steel loss and its effect on the ultimate flexural capacity of RC beams corroded and repaired under load. Construction and Building Materials, 24(6): 1051-1059.
[9]. Auyeung, Y., Balaguru, P. & Chung, L., 2000. Bond behavior of corroded reinforcement bars. ACI Structural Journal, 97(2), pp.214–220.
[10]. Bhargava, K. et al., 2007. Models for Corrosion-Induced Bond Strength Degradation in Reinforced Concrete. ACI Materials Journal, 104(6), pp.594–603.

[11]. Uomoto T, Misra S (1990) Behavior of concrete beams and columns in marine environment when corrosion of reinforcing bars takes place, concrete in marine environments. ACI SP 109–6(1990):127–146.
[12]. R. Huang and C. C. Yang, "Condition Assessment of Reinforced Concrete Beams Relative to Reinforcement Corrosion", Cement and Concrete Composites, 19(1997), pp. 131–137.
[13]. Yoon, S., Wang, K., Weiss, J. and Shah, S. (2000). "Interaction between loading, corrosion, and serviceability of reinforced concrete", ACI Materials Journal, Vol. 97, No. 6, pp. 637– 44.
[14]. Prasath, S. & Selvan, s & Balaji, E... (2017). Experimental study of nano silica and silica fume concrete column subjected to corrosion. 8. 708-719.
[15]. Zapata, L. E., Portela, G., Suárez, O. M., & Carrasquillo, O. (2013). Rheological performance and compressive strength of super plasticized cementitious mixtures with micro/nano-SiO2 additions. Construction and Building Materials, 41, 708–716

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