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EXPERIMENTAL INVESTIGATION OF MECHANICAL PROPERTIES OF RC SHORT COLUMNS EXPOSED TO SODIUM CHLORID AND REPAIRED WITH GFRP.

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Abstract

This paper carries out the effects of sodium chloride on the strength of RC short columns, and evaluates the role of glass fiber-reinforced polymer (GFRP) in enhancing the strength of the column when it is exposed to the penetration of chloride ions. The short columns were prepared with a single concrete mixture of European Standard Cement (EN 197-01:2011, CEM I 42.5 N) having a water-cement ratio of 0.65 and a density of 2356.68 kg/m^3. The columns were constructed with main reinforcements of 3 rods having 10 mm diameter, closed stirrups of 3 mm diameter, and 58 reinforced concrete cylinders cured in varying chloride levels (0%,5%,10%,15%) . While testing, a strict procedure of keeping one group of columns directly in the solution and exposing the other group to wet and dry cycle in difference concentrations of NaCl (5%,10%,15%) with curing time of 28 and 56 days has been followed. The cylinders were repaired and strengthened externally with epoxy bonding by laminating GFRP to the concrete surface. The compressive test was conducted on two groups with duration of 28 and 56 days, in addition to a group that was repaired after 28 days, and later returned to the cured environments and tested them at 56 days. The results showed that the use of GFRP sheets for strengthening reinforced concrete columns, exposed to chloride ions penetrations, is an efficient technique to maintain structural integrity.

In addition, the experimental results of the study have been compared to the numerical results obtained using current constitutive relationships found in the technical literature. In conclusion, it can be stated that the proposed model performs of FRP-confined concrete predicting the ultimate conditions of GFRP-confined samples.

Keywords: Chloride erosion, RC circler short column, Glass fiber polymer (GFRP), Compressive strength

الملخص العربي

يقوم هذا البحث بإجراء تحليل لتأثيرات كلوريد الصوديوم على قوة الأعمدة الخرسانية المسلحة القصيرة ، ويقيم دور البوليمر المقوى بالألياف الزجاجية (**GFRP**) في تعزيز قوة العمود عند تعرضه لاختراق أيونات الكلورايد. تم تحضير الأعمدة القصيرة بمزيج خرساني واحد من الأسمنت القياسي الأوروبي (**EN 197-01: 2011**، **CEM I 42.5N**) بنسبة ماء إلى أسمنت تبلغ 0.65 وكثافة 2356.68 كجم / م^3. تم إنشاء الأعمدة بدعائم رئيسية مكونة من 3 قضبان بقطر 10 مم ، وركاب مغلقة بقطر 3 مم ، و 58 أسطوانة من الخرسانة المسلحة تم معالجتها بتركيزات مختلفة من كلوريد الصوديوم (0٪ ، 5٪ ، 10٪ ، 15٪). أثناء الاختبار ، حيث تمت معالجة مجموعة من الأعمدة مباشرة في محلول كلوريد الصوديوم وتعريض المجموعة الأخرى لدورة ترطيب و تجفيف بتركيزات

مختلفة من كلوريد الصوديوم (5٪ ، 10٪ ، 15٪) مع وقت معالجة يبلغ 28 و 56 يومًا. تم إصلاح الأسطوانات وتقويتها خارجيًا عن طريق تصفيح **GFRP** على سطح الخرسانة. تم إجراء اختبار مقاومة الانضغاط على مجموعتين بمدة 28 و 56 يومًا ، بالإضافة إلى مجموعة تم إصلاحها بعد 28 يومًا ، ثم عادت بعد ذلك إلى البيئات المعالجة واختبارها في 56 يومًا. أظهرت النتائج أن استخدام صفائح **GFRP** لتقوية أعمدة الخرسانة المسلحة المعرضة لاختراق أيونات الكلوريد هي تقنية فعالة للحفاظ على السلامة الإنشائية.

بالإضافة إلى ذلك ، تمت مقارنة النتائج التجريبية للدراسة بالنتائج العددية التي تم الحصول عليها باستخدام العلاقات التأسيسية الحالية الموجودة في الأدبيات الفنية. في الختام ، يمكن القول أن أداء النموذج المقترح للخرسانة المسلحة المحصورة بـ **GFRP** يتنبأ بالظروف النهائية للعينات المحصورة بـ **GFRP**.

INTRODUCTION

Several coastal structures are exposed to physical and chemical deterioration processes, when they are exposed to sea water either directly or indirectly when sea water flood them on the coast. The physical deterioration is caused by crystallization of salts in the pores, while the chemical deterioration is due to the effects of chemical reaction of seawater constituents with cement hydration products [1], in addition to corrosion of embedded steel in reinforced or pre-stressed members, the corrosion of steel reinforcement is one of the main sources of deterioration for the reinforced concrete (RC) structures.

Chloride attack is the chief cause of steel corrosion. It causes widespread damage of the RC structure and results in failure within a short period of service life, where the corrosion accelerates the deterioration of RC structures and lead to cracking and spalling of concrete cover, loss of steel cross-section area, degradation of steel-concrete interface bond[2].

When chloride ions from environmental solutions penetrate into the concrete cover, some of the chloride ions form a chloride binding, which is formed as a result of chloride bonding with the hydration products[3,4], that reduce the porosity of concrete, thus reducing the air voids inside it and increasing its stiffness, and reduces the concentration and flow of free chloride close to the steel reinforcement[5].

A Study by Olutoge and Amusan on the effect of sea water on compressive strength of concrete showed an increase in the compressive strength of concrete for concrete specimens mixed and cured with sea water. In addition, the Compressive strength of the concrete cast with fresh water and cured with salt water and vice-versa was also affected [6] .Another study by O. O. Akinkurolere et.al in 2007[7] suggests that the presence of salt in the mixing and treatment water increases the compressive strength of concrete, while the study of Preeti Tiwari et.al In 2014[8]on concrete cubes compressive strength showed that the rate of strength gain in fresh water cubes is slow compared to salt water cubes. At 28 days, the rate of strength gain is still increasing in all concrete cubes. The fresh water cubes also recorded their maximum strength at 28 days , although the compressive strength of salt water concrete cubes was slightly higher than that of fresh water concrete cubes. According to a study conducted by Islam et al., 2012 [9]The compressive strength increase could last for 28 days It may take up to five years, depending on the study conducted by Mohammed et al., 2004[10]. However, a 37-year study of the Portland Cement Association (PCA) revealed that seawater had no adverse effect on submerged concrete samples, regardless of their cement composition , whereas, concrete placed above high tides suffered more erosion damage than concrete placed at medium tide levels[11]. The influence of seawater and sea sand on the behavior of concrete is still a source of discussion due to the complexity of concrete[12]. However, The main issue is chloride-related corrosion on steel reinforcements in concrete, when the chloride reaches the surface of the intersection zone between the reinforcement steel and concrete, it reduces the PH value and the occurrence of corrosion. Corrosion products will form on the intersection surface and fill the voids and pores of the concrete near the rebar. Since the rust produced as a result of corrosion has a volume 2–4 times larger than that of steel, volume expansion develops tensile stresses in concrete, which ultimately results in cracking and spalling of the concrete cover[13,14, 15].

The complexity of concrete durability problems in concrete structures in coastal environs a serious issue requires high expenditures for maintenance, repair or replacement, and compromises public safety, therefore offering a high resistance materials to the effects of these exposure such as fiber reinforced polymer (FRP) composites, where it is used to strengthen, rehabilitate as well as having resistant to corrosion, weather and chemical, in addition to their advantages such as lightweight and relatively cheap to manufacture ,savings in construction cost and time where that it's easily adapted almost to any shape and size of structure ,durability and their advanced mechanical properties [16],When applicate FRP materials to prevent the penetration of aggressive ions that may be caused a decrease of corrosion rates in the steel bars of reinforced concrete [17],results of study by B. Sena da Fonseca et al that the bars remained in a passive state for longer immersion periods due to the presence of the GFRP that it delayied the diffusion of the solution into concrete and the chloride ion penetration [18], In addition to strength, where many of studies have been conducted to assess the impact of GFRP strengthening on columns, investigated by Muhammad and Shamim[19] shows higher ductility and improved seismic performance can be achieved by retrofitting damaged square concrete columns with GFRP jackets, wherein study by Kumutha et al [20] that using GFRP sheets improving the compressive strength for rectangular concrete columns.

This paper deals the strength of columns that exposed to NaCl, included procedure of repair it with the GFRP and effects of NaCl on repaired columns strength has been discussed.

EXPERIMENTL PROGRAM

Raw materials

Commercially available Ordinary Portland Cement (OPC) classified as CEM I 42.5 N according to European standard EN 197-01:2011, Tunisian standard NT 47-01:2005 and Libyan Standard Specifications 340-2009 F. The fine aggregate used in the experiment was sand with a Specific Gravity of 2.6127, the coarse aggregate with a continuous grade of 5–10mm with a Specific Gravity of 2.68 was used. Use a high adhesion reinforced steel diameter 10mm according to NF A 35 – 016, and hoop Steel 3mm soft rebar. Fiberglass E fabric its strand mat (450 g/m2) (Fig.1), with Sikadur 30 glue (GFRP) was used to repair columns.

Fig. 1 Glass fiber sheet.

Specimens preparation

Mixing was by 0.65 water-cement ratio, where the Concrete mix ratio of C:S:G 1:2.3:2.6 by weight of concrete by electric mixer and the materials were thoroughly mixed in the dry state then added the water according to British method (B.S.1881 part 1970).The fresh concrete mix with 2356.68Kg/m3 wet density was casting in cylindrical steel mould of size 200X100(mm) above three steel reinforcing bars (Fig.2), with a diameter of 10 mm was used in addition to reinforcing of diameter 3 hoops and 10mm concrete cover then compacted by tamping rods, to remove trapped air for each batch, 58 cylinders were cast to be divided among the treatment methods.

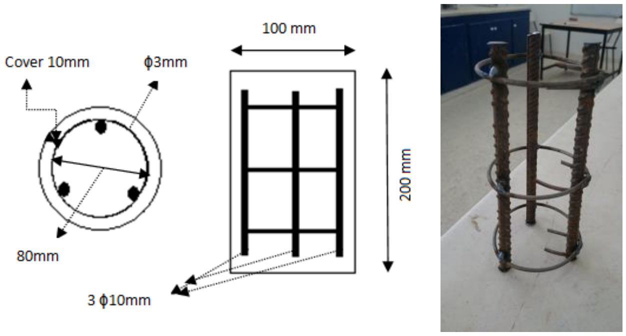

Fig. 2 Steel reinforcement details.

Curing test specimens

It was treated for two periods 28 and 56 days, where the treatment was carried out in three conditions, a group in pure water and considered as the reference samples, a group directly in sodium chloride solution with different concentrations (5%, 10%, 15%) (Fig.3), and the last group was subjected to wet and dry cycles, wetting in different concentrations of chloride solution (5%,10%,15%) for a day and drying in an oven at a temperature of 60°C for two days (Fig.4).

Fig. 3 Curing directly in NaCl (0,5,10,15%).

Fig. 4 Curing wet and dry cycle in NaCl (5,10,15% NaCl; in oven of 60˚C.

Repair by GFRP

After 28 days of curing, three samples from each group that are exposed to sodium chloride solution directly or subjected to wet and dry cycles are repaired and covered after surface drying and applying three layers of GFRP and leaving them to dry completely for two days, Two samples are tested (R28)and compared with The samples that were exposed to the damaged environment with sodium chloride without repair (UR28) and with the reference sample that cured in pure water (C28), While the third sample is returned to the damaged environment in which it was, after it was repaired with GFRP and dried to be tested with the other group after another 28 days (R56(2)) .as shows in (Fig.5).

The same method is applied to the rest of the samples after 56 days of cured, where two samples are repaired and covered after surface drying then covered with three layers of GFRP (R56(1)), then tested and compared with the samples that were not covered by GFRP at the same age 56 days (UR56)as shows in (Fig.6), In addition to the samples that Processed in pure water (C56).That shows in (Table 1).

Fig. 5 Covered column with GFRP.

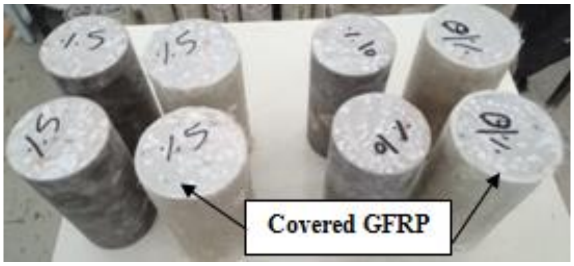

Fig. 6 Repaired(R), unrepaired(UR) samples.

Table 1: Methodology of experimental

Name	Repair with GFRP	Number of samples for difference cuing
C_{28}	Un- Repair	2 in fresh water
C_{56}	Un- Repair	2 in fresh water
UR28	Un- Repair	2 for each concentration of NaCl and (w/d)
R28	Repair	2 for each concentration of NaCl and (w/d)
UR56	Un- Repair	2 for each concentration of NaCl and (w/d)
R56(1)	Repair	2 for each concentration of NaCl and (w/d)
R56(2)	repair after28 day of curing and returned to exposure until tested after 56 day	1 for each concentration of NaCl and (w/d)

Test procedures

The Compression test was carried out according to ASTM C39, it performed by the Compression device shown in the (fig.7) ,on RC cylinder where the force is applied to the sample at a rate of loading 0.5 N/mm2 per second until the failure occurs, The results appear on the computer connected to the Compression machine, where the readings of the curve between the force in KN and the displacement by mm that produced by this force until the failure of the sample occurs.

Fig. 7 Compressive machine.

Fig. 8 Failure mode: a) without cover, b) covered by GFRP.

The test is performed on reference samples (C) and also on samples exposed to damage to NaCl before(UR) and after repairing (R) them with composite materials GFRP, and then comparing results before and after repairing them in terms of their resistance and method of failure, where the test was performed on the concrete cylinder, tested at the curing age of 28 and 56days.

RESULT AND DISSECATION

The effect of sodium chloride salt on the compressive strength of concrete exposed directly to the solution with its different concentrations or exposed to the cycles of wetting and drying, where it was observed in (Fig.9) an increase in the compressive strength of UR56 than of UR28 in all cases, and it was found that the effect of different salt concentrations does not change the strength in UR28 samples compared to the sample that treated in pure water, the change occurred in UR56, with the passage of 56 days, where a significant increase in the resistance value of the samples that treated with sodium chloride solution, especially those that were exposed to the cycles of wetting and drying.

A nearly doubled increase in the value of the compressive strength for the samples that repaired with glass fibers reinforced polymer (R28, R56(1),R56(2)), after exposure to sodium chloride salts, as compared to samples that were not covered after being exposed to sodium chloride (UR28,UR56), in addition to samples that were treated in pure water(C28,C56).

The compressive strength value increased clearly for the samples that were repaired with GFRP, as the compressive strength value for R28 samples (5%, 10%, 15%, 5%w/d, 10% w/d, 15% w/d) increased about (116.9568, 129.8004, 124.5792, 178.1543, 132.5898, 116.5961)% respectively, while R56(2) increased Approximately (97.00513, 104.9948, 86, 78.84909, 73.74976, 111.4532) %, as well as the increased in the compressive strength value of R56(1) samples about (96.02051, 93.16821, 108.913, 109.5846,104.886,113.6105) % respectively.

For the samples R56(2), Where the GFRP were exposed to sodium chloride directly or were exposed to wet and dry cycles, the highest value of the compressive strength was the sample that exposed to the concentration of 15% NaCl with exposure to the cycles of wetting and drying, while the lowest value was for the sample directly exposed to the concentration of 15% NaCl.

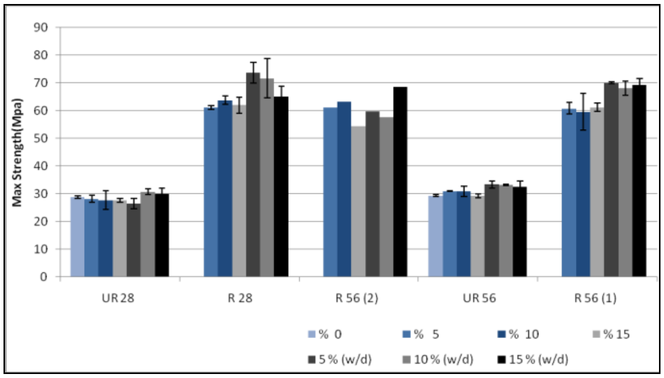

Fig. 9 Effect of covered by GFRP on compressive strength.

Variation in the strain value for different ages when taking into account the effect of sodium chloride salt exposure directly or exposed to wet and dry cycles with its different concentrations, where the strain value increased at UR56 from UR28 for the samples (0%,5%,10%w/d). The increase was noticeable for 5% samples. While the value of the strain at UR56 decreased from the sample at UR28 for the samples (10%, 15%, 5%w/d), while the sample 15%w/d remained with the same strain value for the samples UR28,UR56. As shows in (Fig.10).

The strain value increases significantly for samples that were repaired with GFRP (R28, R56(1),R56(2)), where the strain value for samples (5%, 10%, 15%, 5%w/d, 10% w/d, 15% w/d) at R28 increased by (565.8228, 392.9293, 430.303, 437.8151, 426.4151, 379.646)%, While the value of the samples at R56(1) increased by (363.6364, 434.7826, 497.6744, 426.4151, 378.9916, 340.708)%, And the strain value for R56(2) increased by (532.3232, 444.5652, 330.2326, 437.7358, 369.7479, 405.3097)% respectively.

The strain values in R56(2) gradually decrease by increasing the salt concentration when treating the samples directly in the sodium chloride solution, where the strain values for the samples were 5%,10%,15% (0.00313, 0.002505, 0.00185) respectively, while the strain values were fixed for the samples that exposed to wetting and drying regardless of the Sodium chloride concentration.

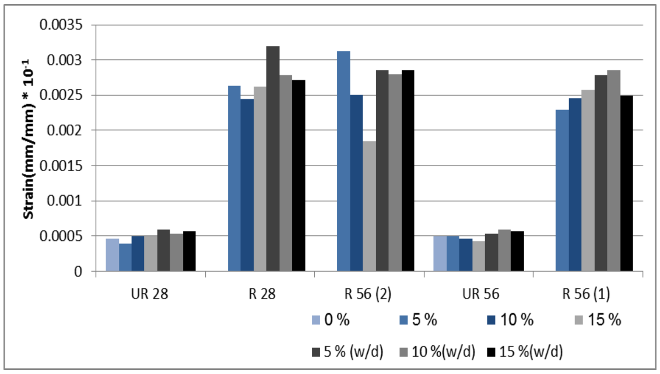

Fig. 10 Effect the repaired by GFRP in exposed columns strain.

MODULS

Many of models of stress-strain is developed for concrete subjected to un axial compressive loading and confined by transverse reinforcement, such as Mander et al (1984) proposed a unified stress-strain mathematical model for predicting the behavior of confined concrete was based, by energy balance method, where this model were basis on the equations that were suggested by Popovics (1973).

Where the effective area which was confined between two steel stirrups based the effective lateral confining pressure, The assumption made in calculating the lateral confinement pressure is that the hoop tension is uniform and exerts a uniform pressure on the concrete. Also, the steel is assumed to have yielded which leads to a constant pressure exerted on the concrete. Hence the relationship that was proposed to compute the lateral confining pressure reflected the fact that the effective lateral confining pressure exerted on the concrete will be a fraction of the confining pressure generated in the stirrup.[21] .In the case of FRP confined for completely wrapped concrete cylinders concrete the effective confined area would be the same as the area between two boundaries of confinement(Fig.11) [22].

The Mander confined concrete stress-strain curve is defined by the following equations:

$$f = \frac{f'_{cc}\,.x.r}{r - 1 + x^{r}}$$

Where:

$$f'_{cc} = f'_{c}\,(2.254.\sqrt{1 + \frac{7.94 f'_{l}}{f'_{c}}} - 2\frac{f'_{l}}{f'_{c}} - 1.254)$$

$$x = \frac{\varepsilon}{\varepsilon'_{cc}} \;,\; r = \frac{E}{E - E_{sec}}$$

$$\varepsilon'_{cc} = [5\left(\frac{f'_{cc}}{f'_{c}} - 1\right) + 1] \;,\; E_{sec} = \frac{f'_{cc}}{\varepsilon'_{cc}}$$

E : Modulus of elasticity (tangent modulus).
E_{sec}: Secant modulus of elasticity.
f'_{c}: Compressive strength of unconfined concrete.
f'_{cc} : Compressive strength of confined concrete.
ε'_{c}: Concrete strain at f'c.
ε'_{cc}: Concrete strain at f'cc.
f'l : Effective lateral pressure on confined concrete provided by the confinement.

The Effective lateral pressure found by the flowing equation:

$$f'_{l} = \frac{2.t.f_{i}}{D}$$

Where:
t: thickness of composite material.
f_{i}: the stress of composite.
D: diameter of cylinder.

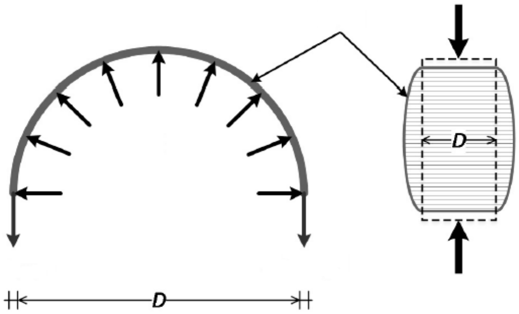

Fig. 11 Stress resistance by GFRP sheet.

When the samples exposed to 5% NaCl solution directly or exposed to wet and dry cycle, the analytical curves shows almost similar behavior to the experimental one, with a clear difference in the value of the analytical strain at the age of 56 from the experimental one for the same age. As shows in (Fig.12)

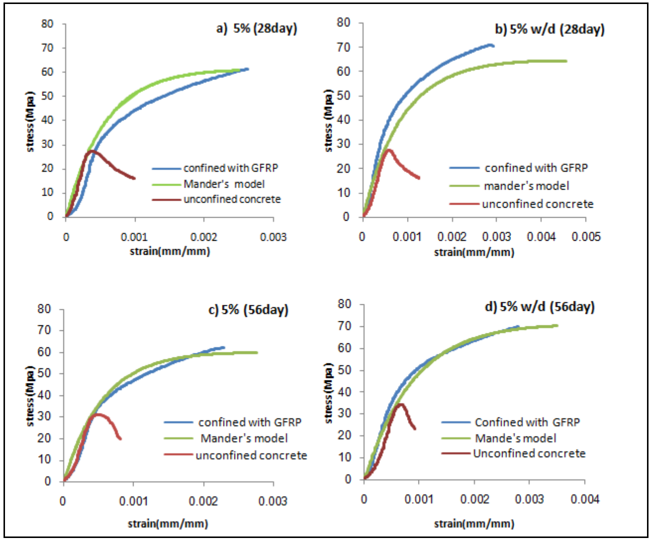

Fig. 12 Stress strain curves for experimental and modeled result for samples that exposed to (5%) NaCl then covered by GFRP.

(Fig.13) shows the samples that exposed to 10% NaCl directly or exposed to wet and dry cycle, it;s clear that the analytical curve was similar to the experimental one, with a clear difference in the strain value.

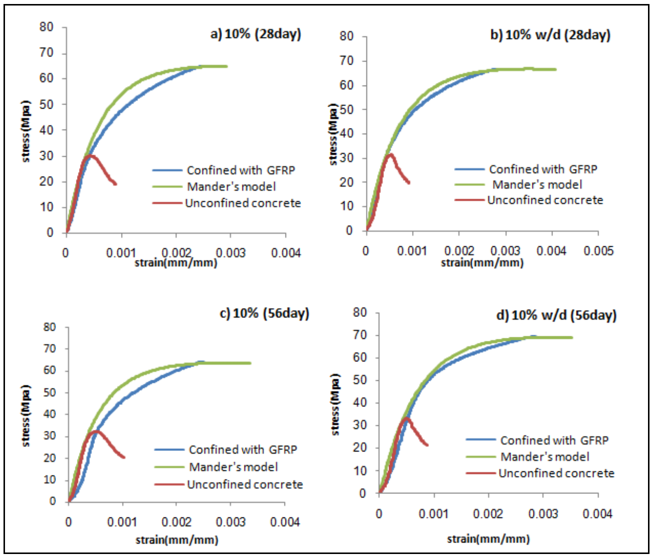

Fig. 13 Stress strain curves for experimental and modeled result for samples that exposed to (10%) NaCl then covered by GFRP.

While in samples that exposed to 15% NaCl directly or exposed to wet and dry cycle, (Fig.14) shows that at the age of 28 days, the value of the analytical stress is approximately identical to the curve, but the value of the analytical strain is higher than its actual value, while at the age of 56, the value of the strain coincides with a difference in the shape of the curves. However, the samples subjected to the wetting and drying cycles of the two ages are similar to the shapes of the analytical and experimental curves with a difference in the value of the analytical strain from the experimental with a noticeable difference.

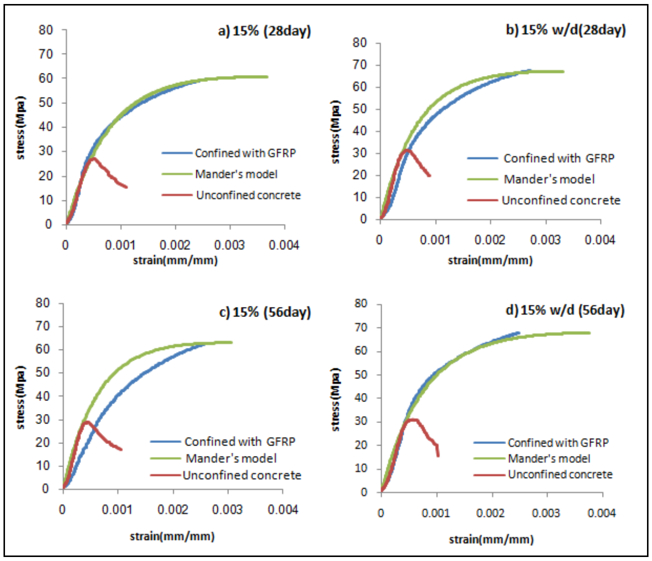

Fig. 14 Stress strain curves for experimental and modeled result for samples that exposed to (15%) NaCl then covered by GFRP.

The performance of the proposed analytical model for stress strain curve, where the shape of the analytical curves is almost the same as the experimental curves, or its give a index for the point that fail on it.

CONCLUTION

In this study 58 short reinforced columns were studied, where they were presented to a solution of sodium chloride with different concentrations and ages and compared with samples cured in pure water, in addition to wrapping and covered them with three layers of glass fibers after exposure to chloride.

Based on the results, the various outcomes of the study are outlined below:

- The compressive strength of samples cured in sodium chloride solution is higher than that of samples cured in pure water, and it increases significantly at the age of 56 days.
- Regarding the compressive strength of samples that were covered with glass fibers GFRP after exposure to chloride, it increased by double for different curing ages and NaCl salt concentrations.
- While the compressive strength increased for the samples that were covered with glass fibers and returned to the damage environment in which they were present, meaning that the glass fibers were not damaged by the concentrations of sodium chloride and the treatment method.
- For the Mandir principle to estimate the value of the compressive strength of samples damaged by sodium chloride and then wrap them with glass fibers reinforcement polymer, it gives values for the maximum strength that the columns can reach, but the value of the strain varies, that is, it gives an

indication of the behavior of samples after covered by GFRP.

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