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Performance of hybrid bars in corrosion and flexure in concrete beams

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Abstract:
Corrosion of reinforcing steel is a serious problem worldwide; the problem of steel rebar corrosion leads to a reduction in the lifespan of the structure and adds to the maintenance costs. Many techniques have been developed in recent past to reduce corrosion but none of these solutions seem to be applicable as an adequate solution to the corrosion problem. Besides the use of Fiber Reinforced Polymer (FRP) rebar, hybrid rebar consisting of both FRP and steel are also being tried to control the problem of steel corrosion. This research evaluates the performance of hybrid rebar in corrosion resistance by inducing natural corrosion in a number of concrete cylinders with a hybrid rebar embedded symmetrically. The research also studies the performance of hybrid rebar as a tension reinforcement in concrete beams.

ملخص البحث:

يعتبر الحديد هو الماده الأكثر شيوعا فى الاستخدام كصلب تسليح فى العناصر الخرسانيه وذلك بسبب تكلفته المناسبه وخصائصه الميكانيكيه العاليه. ولكن امكانيه تعرض الحديد للصدأ تعتبر مشكله هامه حيث تقلل من عمر المنشأ وتعمل على زياده تكلفه الصيانه للمنشأ. تم تطوير العديد من الطرق لحمايه حديد التسليح وتقليل خطر اصابته بالصدأ ولكن لم يتم التوصل الى حل مناسب للتخلص من مشكله الصدأ نهائيا. مؤخرا تم استخدام الفايبر كأسياخ تسليح بديله لاسياخ الحديد بغرض تفادى مشكله الصدأ . بالاضافه الى انه تم تجربه استخدام اسياخ هجينه مكونه من اسياخ حديد ملفوفه بلفات من الفايبر وذلك لحمايه الحديد من الصدا والاستفاده من خصائص الحديد والفايبر معا. هذا البحث يدرس سلوك الاسياخ الهجينه فى مقاومه الصدأ عن طريق تجهيز عينات اسطوانيه تحتوى على سيخ هجين فى مركز الاسطوانه وتعريضها لبيئه تحاكى الصدأ الطبيعى .ايضا يقوم هذا البحث بدراسه سلوك الاسياخ الهجينه كحديد تسليح للكمرات الخرسانيه .

***Keywords*: **Fiber Reinforced Polymer; Flexure and Corrosion.

1. INTRODUCTION

Corrosion of steel in reinforced concrete structures is a major problem which leads to a reduction in the lifespan of the structure and adds to the maintenance cost. Recently advanced composite materials such as Glass Fiber Reinforced Polymer (GFRP) and Carbon Fiber Reinforced Polymer (CFRP) have become an attractive substitute for steel reinforcement, as these materials are non-corrosive, have a high strength-to-weight ratio, and commercially available at reasonable cost [1,2]. Although FRP is a non-corrosive material, it has some common shortcomings such as low elastic modulus, low shear capacity. Hybrid bars have been developed as a way to enhance the performance of FRP, utilize the anti-corrosion property, and to resolve the problem of durability of RC structure and brittle failure of FRP structure by combining the advantages of steel bars and FRP together. Some of other advantages of a Steel-Fiber Reinforced Polymer composite bar (SFCB) is that the pultrusion process and ribbed inner steel bar ensures favorable interface properties and therefore full use of each material, it also ensures high ultimate strength, high elastic modulus and obvious post-yield modulus in the stress-strain relationship after the inner steel bar yields. Second, the bond strength between SFCB and concrete is favorable and can be improved by modifying surface parameters. Whether the inner steel bar of the SFCB yielded before pulling out was determined by the FRP type, the steel/FRP ratio, the effective bond length and the concrete strength [3]. In earlier studies bond between the FRP reinforcement and concrete was achieved through the use of sand coating on the surface of the rebars [4] or through a secondary surface treatment of the rebars [1,5]. With the same favorable anti-corrosion capacity as FRP bar, SFCB has a smaller cost. By adjusting the steel/FRP ratio and FRP type in SFCB, good ductility can be assured [3]. This study evaluates the performance of hybrid bars in corrosion resistance, and the performance of hybrid rebar as a tension reinforcement in concrete beams under flexure loading.

2. EXPERIMENAL PROGRAM

In this study, the performance of hybrid rebar in corrosion was investigated by Producing natural corrosion in a number of concrete cylinders with a hybrid rebar embedded centrally using aggressive environment. The performance of hybrid rebar as a tension reinforcement in concrete beams was also investigated by testing three beam specimens and comparing their results with each other.

2.1 TESTED SPECIMENS

Natural corrosion was produced in a number of concrete cylinders with a hybrid rebar embedded centrally as shown in Fig. 1 to evaluate the performance of hybrid bars in corrosion resistance. All details of the test specimens are shown in Table 1. concrete beams were casted measuring (180 mm x 250mm in cross section x 1500 mm in length) reinforced with hybrid Steel-Fiber Reinforced Polymer composite bar (SFCB) to test the performance of hybrid rebar as a tension reinforcement compared to a control beam with the same dimensions, reinforced with ordinary steel bars. as shown in Figs.(2,3, and 4). All details of the test specimens are shown in Table 2.

2.2 SPECIMENS PREPERATION

The molds were prepared and assembled in order to fulfill the required dimensions of the specimens of each test. After the steel reinforcement were installed, concrete mix was placed then the concrete was vibrated mechanically and the concrete surface was finished. Concrete specimens were removed from the molds and then cured. The corrosion test specimens were exposed to accelerated natural corrosion condition and resulted in severe corrosion damage.

2.3 MATERIAL PROPERTIES

Suitable mix of 29.5 MPa cubic compressive strength after 28 days were used. High tensile steel bars 10 and 12mm diameter were used as tensile reinforcement. Normal mild steel bars 8 mm diameter were used for stirrups and top reinforcement in beam specimens. The hybrid rebars used consisted of FRP sheets (Glass / Carbon), rolled on a steel rod, with the help of an epoxy binder material. The adhesive used for bonding FRP sheets to steel was a compatible epoxy.

Fig.1: Corrosion test specimens.

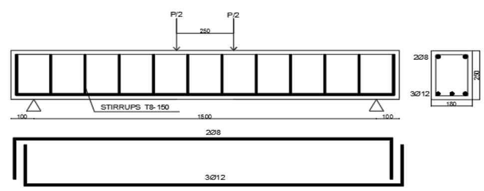

Fig.2: Beam 1.

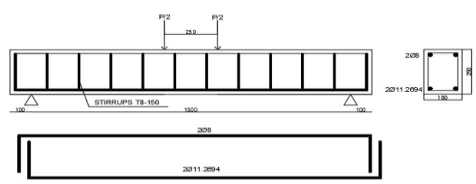

Fig.3: Beam 2.

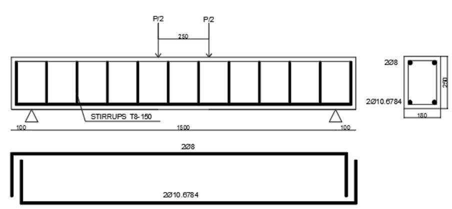

Fig.4: Beam 3.

Table (1): Corrosion test specimens.

Cylinder Dimensions (mm)	FRP Type	No. of FRP layers around the steel bar	Diameter of steel bar (mm)
50 x 300	--------------	--------------	10
50 x 300	Carbon	1	10
50 x 300	Carbon	2	10
50 x 300	Glass	1	10
50 x 300	Glass	2	10
100 x 300	--------------	--------------	10
100 x 300	Carbon	1	10
100 x 300	Carbon	2	10
100 x 300	Glass	1	10
100 x 300	Glass	2	10
150 x 300	--------------	--------------	10
150 x 300	Carbon	1	10
150 x 300	Carbon	2	10
150 x 300	Glass	1	10

Table (2): Flexure test specimens.

Beam Specimen	Type of Rebar	Longitudinal Reinforcement	Transverse Reinforcement
Beam 1	Steel	3-12 mm and 2-8 mm	8mm-2legged@150 mm
Beam 2	Steel-GFRP	2-11.2694 mm and 2-8 mm	8mm-2legged@150 mm
Beam 3	Steel-CFRP	2-10.6784 mm and 2-8 mm	8mm-2legged@150 mm

2.4 TEST SETUP AND TESTING PROCEDURE

For beam specimens the load was applied, and the readings were recorded on excel sheet on computer. The applied load was equally distributed on two concentrated points using spreader beam. The specimens were prepared for testing as a simply supported under three points bending. The beams were simply supported over a clear span of 1500 mm. A spreader beam was used to transfer the load to the test specimen through two loading points 250 mm in mid span of beam. Three linear variable displacement transducers (LVDTs) mounted at the bottom soffit of the beam for measuring deflections at bottom face of the beams (tension side), placed at the mid-span and under the two load application points. Vertical deflection, and ultimate failure load, were recorded. Cracks propagation was monitored after each load increment up to failure. For the corrosion test The corrosion behavior of steel in concrete was studied by applying three types of electrochemical measurements, these were:

1) Open circuit potential measurements:

The tendency of any metal to react with an environment is indicated by the potential that develops in contact with the environment. In reinforced concrete structures, concrete acts as an electrolyte and the reinforcement will develop a potential depending on the concrete environment. The principle involved in this technique is essentially the measurement of corrosion potential of the steel rebar (working electrode) with respect to a standard reference electrode such as saturated calomel electrode (SCE). The steel potential has been measured along a test duration of 180 minutes with a spacing between the data points of 1 minute.

2) Linear polarization (polarization resistance) technique:

This technique makes it possible to measure the corrosion rate of a metal at any instant. In the linear polarization measurement of steel reinforcement, the steel potential is perturbed by a small amount away from its equilibrium value.

3) Concrete resistivity measurement:

The electrical resistivity of concrete is an important parameter concerning determination of intensity of the initiated corrosion process. In concrete material with high electrical resistivity the corrosion process will be slow compared to concrete with low resistivity in which the current can easily pass between anode and cathode areas. In concrete resistivity measurement, a known current "I" is impressed and the resulting potential drop "V" is measured and the resistance "R" is given by (V/I).

Corrosion resistivity (ρ) = $2\pi aR$

Where, (a) is the electrode distance in (cm).

(R) is the measured resistance in (Ohm).

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 FLEXURE TEST

Concrete beams casted were measuring (180 mm x 250 mm in cross section x 1500 mm in length) reinforced with hybrid Steel-Fiber Reinforced Polymer composite bar (SFCB) to test the performance of hybrid rebar as a tension reinforcement compared to a control beam with the same dimensions, reinforced with ordinary steel bars. The results were recorded as shown in Table 3. Beam 1 having longitudinal and transverse steel bars were used as a control beam. Beam 2 was reinforced with longitudinal Steel-Glass Fiber Reinforced Polymer Composite Bars and steel stirrups. Beam 3 was reinforced with longitudinal Steel-Carbon Fiber Reinforced Polymer Composite Bars and steel stirrups.

3.1.1 COMPARISON BETWEEN MODES OF FAILURE.

The mode of failure observed for beam 1 was flexure-tension failure as shown in Fig.5. The mode of failure observed for beam 2 was flexure-tension failure as shown in Fig.6. Splitting of concrete at the reinforcement level was observed. The mode of failure observed for beam 3 was flexure-tension as shown in Fig.7. Splitting of concrete at the reinforcement level was observed.

Fig.5: The mode of failure observed for beam 1

3.1.2 COMPARISON BETWEEN LOADS AT FAILURE

Beam 1 failed at a load higher than the target design load. Beam 2 failed at a load less than the target design load and less than the failure load of beam 1. Beam 3 failed at a load less than the target design load and less than the failure load of beam 1 but it is higher than the failure load of beam 2.

3.1.3 COMPARISON BETWEEN DEFLECTIONS VALUES AT FAILURE

For beam 1 the deflection value at failure was less than the expected deflection value. For beam 2 the deflection value at failure was less than the expected deflection value but higher than the deflection value of beam 1. For beam 3 the deflection value at failure was less than the expected deflection value and less than the deflection value of beam 1 but equal to the deflection value of beam 2. Fig.8 shows Load v/s deflection in beam specimens.

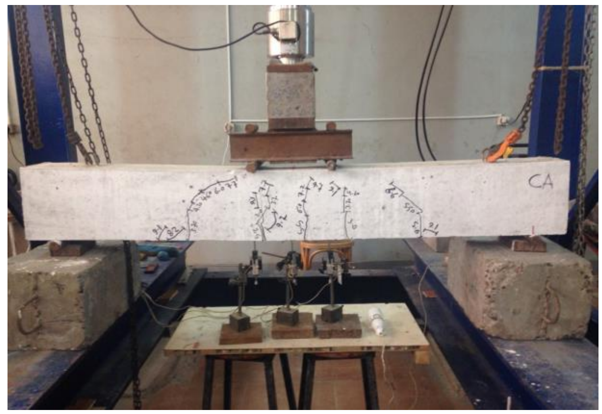

Fig.7: The mode of failure observed for beam 3.

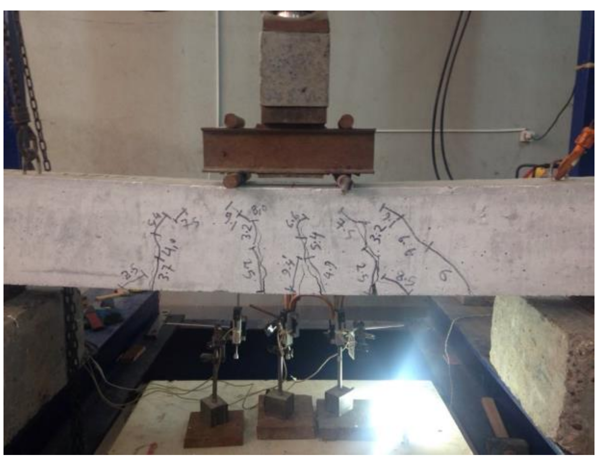

Fig.6: The mode of failure observed for beam 2.

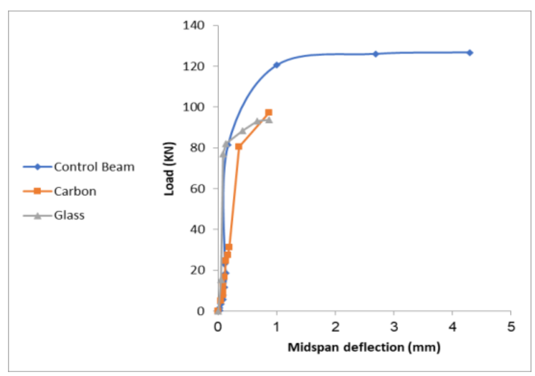

Fig.8: Load v/s deflection in beam specimens.

Table (3): Flexure Test Results.

Beam Specimen	Type of load	Target Design	Experimental Results
Beam 1	Applied load at failure (kN)	112	126
	Deflection at failure (mm)	2.11	0.168
Beam 2	Applied load at failure (kN)	112	94
	Deflection at failure (mm)	2.11	0.869
Beam 3	Applied load at failure (kN)	112	97
	Deflection at failure (mm)	2.11	0.869

3.2 CORROSION TEST

The corrosion test specimens were exposed to accelerated natural corrosion which resulted in severe corrosion damage. The corrosion behavior of steel in concrete was studied and the results are shown in Tables 4, 5 & 6. The tables show that Steel-Fiber Reinforced Polymer composite bars (SFCB) are effective in corrosion resistance as they showed better results than the ordinary steel bars. It was noticed that the resistivity to corrosion increases as we increase the diameter of the cylinder, and the number of fiber rolls around the steel bar.

Table (4): 50x300 mm concrete cylinders test results.

Specimen No.	Type of rebar	linear polarization resistivity Rp			O.C.V Results	RP
		Icorr (μA/cm2)	Ecorr (mV)	Corrosion rate (mm/year)	Ecorr (mV)	Ohm (Ω)
1	Steel bar	20.17	-556.90	4.09e-3	-245	4700
2	Steel-CFRP (one roll of FRP)	7.17	-464.26	2.09 e-3	-235	5430
3	Steel-CFRP (two rolls of FRP)	3.46	-441.37	1.01e-3	-225	7293
4	Steel-GFRP (one roll of FRP)	3.72	-449.93	1.08 e-3	-230	5990
5	Steel-GFRP (two rolls of FRP)	1.81	-422.92	0.88 e-3	-150	7911

Table (5):100x300 mm concrete cylinders test results.

Specimen No.	Type of rebar	linear polarization resistivity Rp			O.C.V Results	RP
		Icorr (µA/cm2)	Ecorr (mV)	Corrosion Rate (mm/year)	Ecorr (mV)	Ohm (Ω)
1	Steel bar	10.17	-464.26	4.09 e-3	-230	4700
2	Steel-CFRP (one roll of FRP)	1.46	-349.93	1.08 e-3	-225	7870
3	Steel-GFRP (two rolls of FRP)	1.01	-341.37	0.88 e-3	-150	9911
4	Steel-CFRP (one roll of FRP)	1.08	-342.92	1.01 e-3	-200	9293
5	Steel-GFRP (two rolls of FRP)	0.426	-320	0.58 e-3	-100	19000

Table (6):150x300 mm concrete cylinders test results.

Specimen No.	Type of rebar	linear polarization resistivity Rp			O.C.V Results	RP
		Icorr (µA/cm2)	Ecorr (mV)	Corrosion Rate (mm/year)	Ecorr (mV)	Ohm (Ω)
1	Steel bar	9.61	-364.26	2.09e-3	-225	8809
2	Steel-CFRP (one roll of FRP)	0.55	-264.77	0.16e-3	-150	12493
3	Steel-CFRP (two rolls of FRP)	0.45	-257.17	0.13e-3	-138	15460
4	Steel-GFRP (one roll of FRP)	0.49	-260.14	0.14e-3	-140	14434
5	Steel-GFRP (two rolls of FRP)	0.37	-253.16	0.10e-3	-130	18060

4. CONCLUSIONS

The following conclusions emerge from the present study:

1. For the flexure test greater deflections were observed for hybrid rebar reinforced concrete specimens due to their lower modulus of elasticity compared to those of conventional steel reinforced beams for the same load.
2. Failure of hybrid rebar reinforced beams was primarily due to concrete cover separation at the level of reinforcement, resulting in loss of bond between rebar and concrete. The above mode of failure must have led to their premature failure.
3. For the corrosion test the results showed that Steel-Fiber Reinforced Polymer composite bars (SFCB) are effective in corrosion resistance as they showed better results than the ordinary steel bars.
4. It was noticed that the resistivity to corrosion increases as we increase the diameter of the cylinder, and the number of fiber rolls around the steel bar.

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