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The Behavior of Concrete Slabs Reinforced with Basalt Fiber Bars

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ملخص البحث

يعتبر حديد التسليح العنصر الأكثر إستخداماً في المنشآت الخرسانية وخاصة في مصر لما له من مميزات مثل الممطولية ومقاومته النسبية للحريق غير إن صدأ الحديد يعتبر أحد المشاكل الرئيسية في إستخدامة وخاصة في المنشآت المهمة والمعرضة بصفة مستمرة لعوامل الرطوبة مثل الكباري وبلاطات الأسطح وخزانات المياة ولتجنب التكلفة العالية للصيانة وصعوبة إجرائها والتاثير السيئ علي خصائص الخرسانة ولهذه الأسباب جرت عدة محاولات للتغلب علي هذه المشكلة منها إستخدام المواد المركبة كبديل لحديد التسليح وذلك لمقاومة الصدأ وأعطيت نتائج جيدة ولكن من ناحية أخري كان لها بعض العيوب من أهمها امتلاكها لمعامل مرونة منخفض مقارنة بالحديد ولتحسن هذه الخاصية تم إستيراد أسياخ مصنوعة من الالياف البازلتية و إستخدامها في تسليح البلاطات الخرسانية بنسب مختلفة وذلك للإستفادة من مميزات الألياف البازلتية من حيث رخص ثمنها وممطوليتها العالية نسبيا.

ABSTRACT

The advances in fiber-reinforced-polymer (FRP) technology have spurred interest in introducing new fibers, such as basalt, in addition to the commonly used glass, carbon, and aramid. Recently, new basalt-FRP (BFRP) bars have been developed, but research is needed to characterize and understand how BFRP bars would behave in concrete members. This paper presents an experimental aimed to study the behavior of concrete slabs reinforced with imported BFRP-bars and polypropylene fibers added to the concrete mix. This Research focused on the application of the BFRP-bars as reinforcement of concrete slabs. A nine slabs specimen was tested to evaluate the influence of using BFRP-bars instead of the traditional steel reinforcement. Several parameters were considered in this research such as reinforcement ratio, compressive strength and addition of the polypropylene fibers to the concrete mix. The polypropylene fibers were added to the concrete mix to improve the behavior of the slabs. The program was done at the Materials Testing Laboratory of the Faculty of Engineering Mataria, Helwan University, Cairo by using most of the materials available in the Egyptian market. Using imported BFRP-bars with diameters of 12 mm with length of 2000 mm and tested under two-point bending.

KEY WORDS:
Basalt, Basalt Fiber Rebars (BFRP), Polypropylene, Deflection, Compressive Strength.

1. INTRODUCTION

In 1960`s corrosion problem of steel reinforced concrete structures exposed to aggressive environments such as roofs, liquid reservoirs, parking areas, bridges, foundations ... etc. had been started to be a nagging problem for engineers, since then finding solutions to overcome this challenging problem became a very attractive area for research. For example, in Canada it is estimated that the repair cost of parking structures is in the range of four to six billion dollars [4]. Also the cost estimation of repairing the existing highway bridges in USA is found to be over 50 billion dollars and one to three trillion

dollars for all concrete structures [6]. Extreme corrosion problems also found in Arabian Gulf countries [9]. Due to this expensive costs and difficulty performing maintenance for these structures, and consequently the bad effects on concrete that results in deterioration, it became a must for researchers to deal with the corrosion problem before it begins. There is a suggested solution by replacing the steel reinforcement with a non-corrosive material. Fiber reinforced polymer (FRP) is such that material which gained a wide acceptance due to its unique characteristics such as high tensile strength, low density, and high corrosion resistance coupled with non-conductive magnetic characteristics.
The application of BFRP-bars as reinforcements for concrete elements are not yet well established in neither Egypt nor in the Middle East.

The main reasons for this Limited use are that these bars are imported from other regions such as Europe, China, or the United States. This leads to an extremely high cost products and dictates to produce BFRP–bars locally. This will encourage local manufactures to adopt the process of making these bars for the Egyptian market.
FRP can be defined as a composite made from fiber reinforcement embedded in a plastic (polymer) matrix. The mechanical and physical properties of FRP depend on the fibers type and resins which is used to form the composite. These differences result from the mechanism of interaction between FRP reinforcement bars and concrete. It is found that the concrete reinforced with FRP-bars has larger deflections and wider cracks than the ordinary reinforced concrete elements. There are many researches and tests of using basalt fibers into concrete structures, mainly concrete beams. The tests show improvements in strength and durability. In this thesis the focus will be on the basalt fiber bars, the possible usage of such these bars instead of the common steel reinforcement bar [15].However, there are some disadvantages for FRP materials. They have low shear and compressive strength compared to the same properties of steel. The same applies for the modulus of elasticity, which is considerably lower for the cheapest FRP materials, GFRP and BFRP, than for steel [16].In the literature, each parameter was dealt with individually.
Some experiments were performed on beams (few on slabs) with polypropylene fibers added to the concrete mixture. Other work dealt with structural elements reinforced with FRP-bars. Very few works have dealt with elements including both parameters. In this work, slabs reinforced with BFRP-bars and made of concrete mixture with polypropylene fibers added to it are the key structural elements whose behaviour is investigated. Several measurements are included in this study to compare between regular slabs (R.C. Slab with steel bars and ordinary concrete mixture) and slabs reinforced with both BFRP-bars and polypropylene fibers.

2 Experimental Program

2.1 Material

The Basalt fiber reinforcement polymers (BFRP)-bars are imported from HBGMEC Company in China (Huabin General Machinery & Equipment Import & Export Co, Ltd). The Company provide us with data sheets which containing all of the Properties of these rebars. It provides us also with the component of the rebars and the method of fabrication. All these Points will be discussed in our research.

2.2 Concrete Mixture and Proportions

The Slabs specimens were made with ready-mixed, normal strength concrete with a target compressive strength of 25, 30, 35 MPa. The mix proportions of the target compressive strength are shown in the following Tables:

	Mix proportions			
Volume m3	Water kg/m3	Cement kg/m3	Coarse aggregate kg/m3	Fine Aggregate kg/m3
1	210	385	1220	535
0.12	45.4	83.2	263.5	115.6

Table 1: Mixture Proportion of Slabs with 25MPa Compressive Strength

	Mix proportions			
Volume m3	Water kg/m3	Cement kg/m3	Coarse aggregate kg/m3	Fine Aggregate kg/m3
1	210	400	1253	537
0.12	45.4	96.6	262.7	107.3

Table 2: Mixture Proportion of Slabs with 30MPa Compressive Strength

	Mix proportions			
Volume m3	Water kg/m3	Cement kg/m3	Coarse aggregate kg/m3	Fine Aggregate kg/m3
1	210	428.5	1189	572.5
0.12	45.4	92.6	256.8	58.9

Table 3: Mixture Proportion of Slabs with 35MPa Compressive Strength

2.3 Description of Slabs specimens

The experimental program of this research focused on studying the behavior of concrete slabs reinforced with imported BFRP-bars and polypropylene fibers added to the concrete mix. This Research focused on the application of the BFRP-bars as reinforcement of concrete slabs. The polypropylene fibers were also added to the concrete mix to improve the behavior of the slabs. The experimental program was done at the Materials Testing Laboratory of the Faculty of Engineering Mataria, Helwan University, in Cairo by using most of the materials available in the Egyptian market. Using imported BFRP-bars with diameters of 12 mm with length of 2000 mm.

The experimental program examined the effect of different parameters on the behavior of the concrete slabs. These parameters were:

1. Bars type: Steel, and Basalt fibers.
2. Three reinforcement percentages. (i.e. The slabs are reinforced by 6 and10 bars /m which give reinforcement ratios of 0.57% and 0.94% respectively).
3. Amount of polypropylene fibers added to the concrete mix: (1 and 2kg/m^3).
4. Compressive strength of the concrete: (30 and 35 N/mm2).

Group	Slab No.	No. of RFTbars	Diameter (mm)	Material	Fcu N/mm²	Polypropylene Fibers/m³
I	S1	3	12	Steel	25	0 kg
II	S2	3	12	BFRP	25	0 kg
	S3	5	12	BFRP	25	0 kg
III	S4	3	12	BFRP	25	1 kg
	S5	3	12	BFRP	25	2 kg
IV	S6	3	12	BFRP	30	0 kg
	S7	3	12	BFRP	35	0 kg

Table 4: Description of Tested Slabs

2.4 Test set-up and instrumentation

The specimens were placed between the jack heads and the steel frames under quasi-static displacement control technique centered with its axis using two bearing plates to ensure uniform load distribution. Then, the strain gages were connected to the data acquisition system attached to the computer. Before loading, zero loading of steel strain and vertical concrete displacements were recorded and checked. The electrical instrumentation readings were initialized to zero using the testing software of the data acquisition system. The load was applied gradually with constant rate of loading during the test. The data acquisition system recorded continuous readings of the electrical load cell; the electrical pressure sensor; the LVDTs that measure the slab deflections. At the displacement peaks, the readings of the electrical strain gages were recorded and the system was pausing for 10 second to allow monitoring the cracks. For some specimens, some readings after failure loads (unloading zone) up to 25 % of maximum loads were recorded. Because the machine had no displacement control capabilities, this operation was made manually using variable load increment.

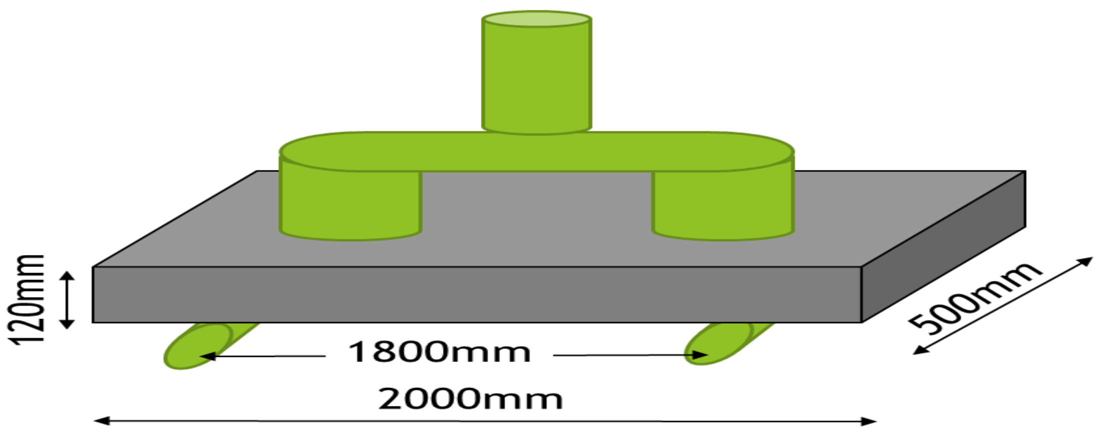
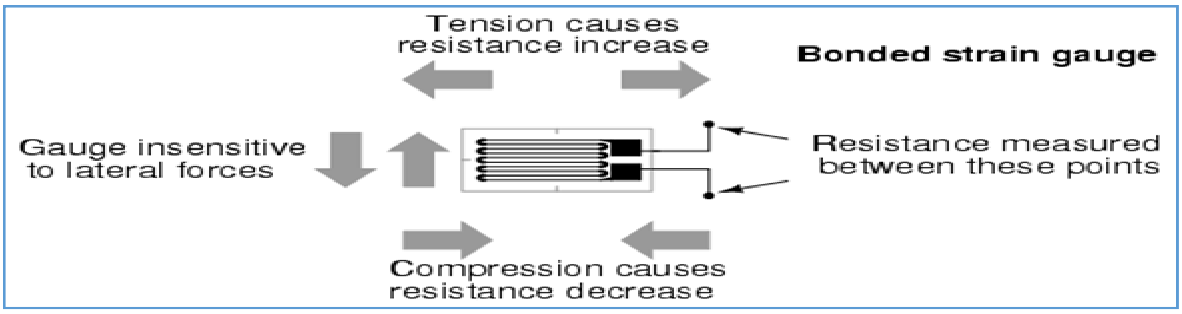


Figure 1: Test set-up

2- 4-1 Strain gauge

A strain gage (sometimes referred to as a Strain gauge) is a sensor whose resistance varies with applied force; it converts force, pressure, tension, weight, etc., into a change in electrical resistance which can then be measured. When external forces are applied to a stationary object, stress and strain are the result. Stress is defined as the object's internal resisting forces, and strain is defined as the displacement and deformation that occur.



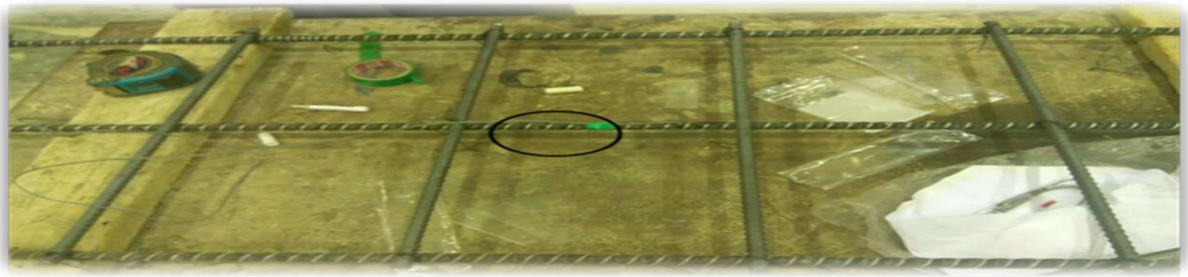


Figure 2: Strain gauge

2.4.2 Deflection Devices

To record vertical deflections, vertical LVDTs were used below slab-column specimens at two locations spaced.

Figure 3: LVDT Devices

3. Results and Discussion

All the specimens were tested after 28 days. The specimens were loaded and several measures were assessed. The load was increased monotonically till failure. The vertical displacements were measured at each level of loading at mid span. While the crack distribution was recorded. Also the strains in the reinforcement were measured at each loading step. The behaviors of the slabs were evaluated by studying the following:-

1 - The crack patterns and the modes of failure.
2- The load - deflection relationship.
3- The cracking and failure loads.
4- The deflected shape.

3-1 - The crack patterns and the modes of failure

Crack patterns at failure load in the middle of the span, for slabs shown in figures (from 4 to 10).

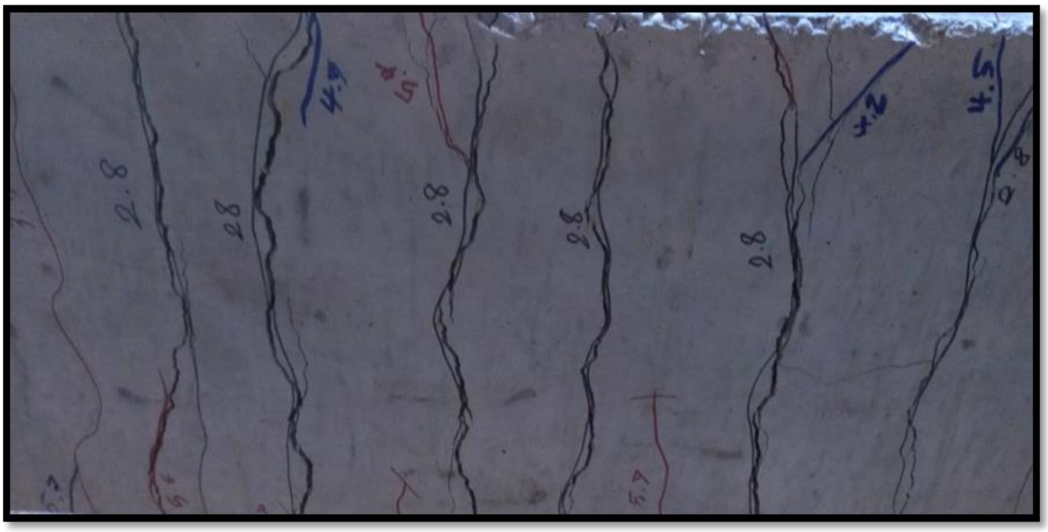


Figure 4: Cracks Distribution for S1

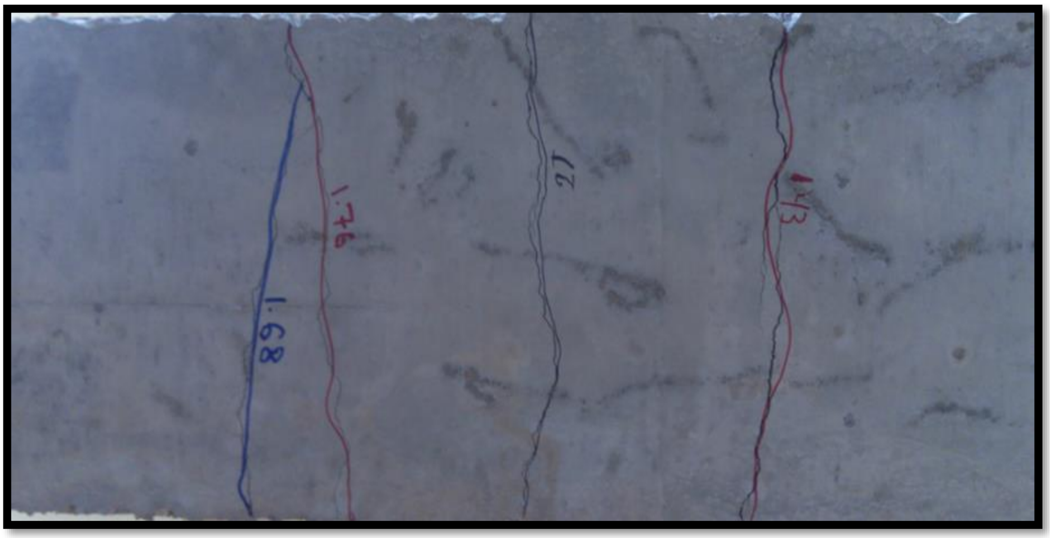


Figure 5: Cracks Distribution for S2

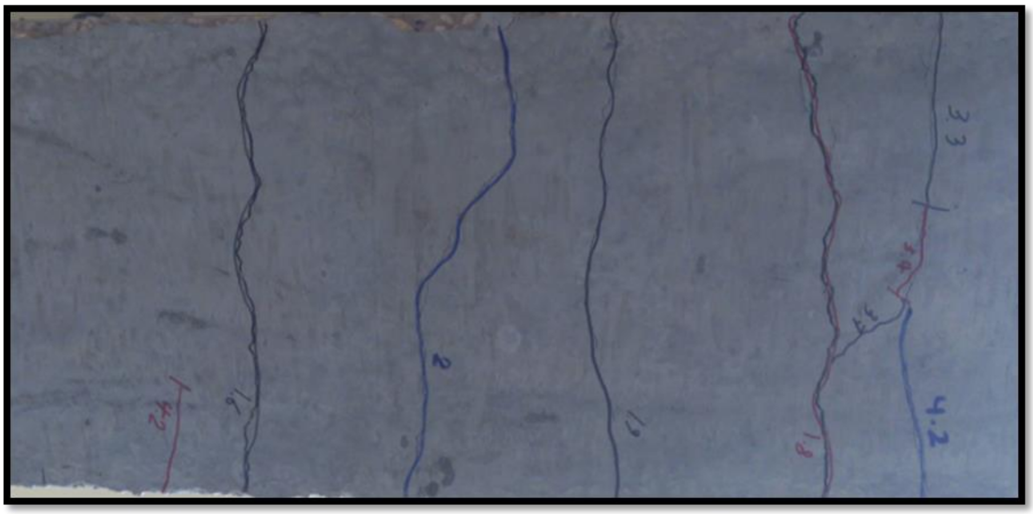


Figure 6: Cracks Distribution for S3

Figure 7: Cracks Distribution for S4

Figure 8: Cracks Distribution for S5

Figure 9: Cracks Distribution for S6

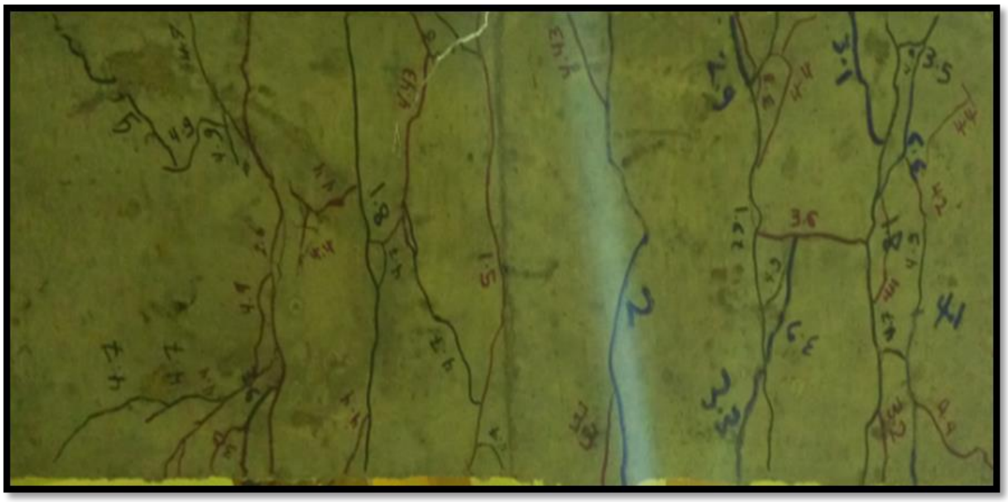


Figure 10: Cracks Distribution for S7

3-2 The load - deflection relationship

Figures from (11 to 17) show the load mid-span vertical-deflection of the specimens. This relationship was constructed using the deflection at the slab and the loading.

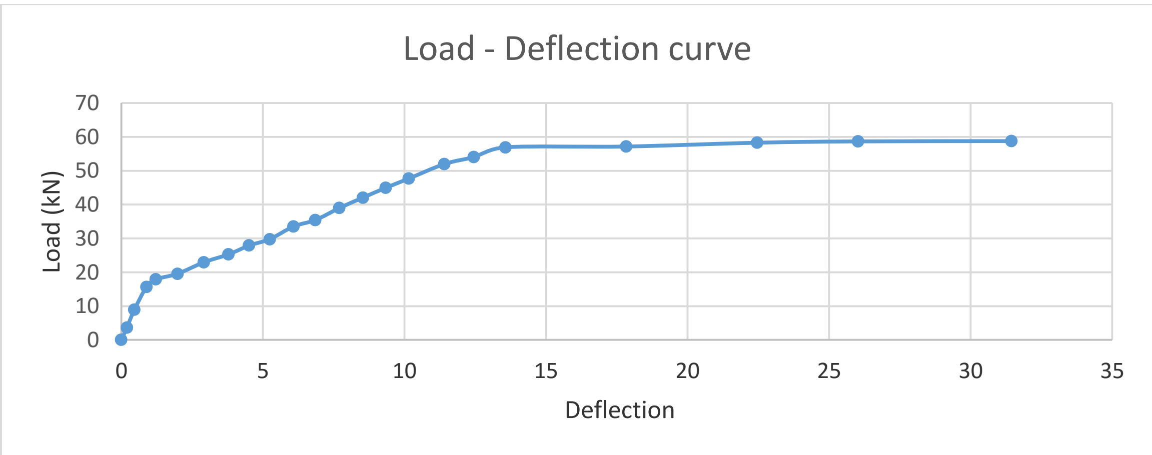


Figure 11: Load – Deflection Curve for Slab S1

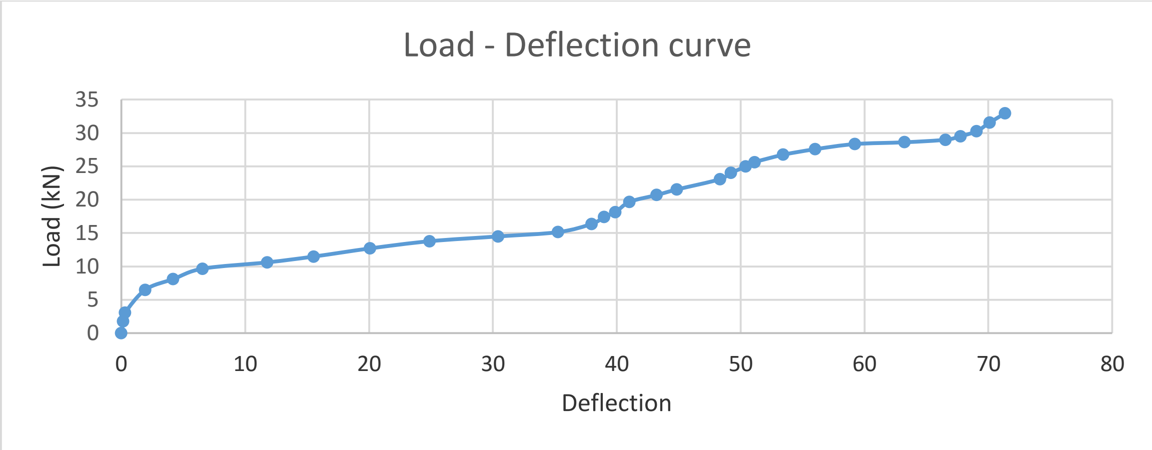


Figure 12: Load – Deflection Curve for Slab S2

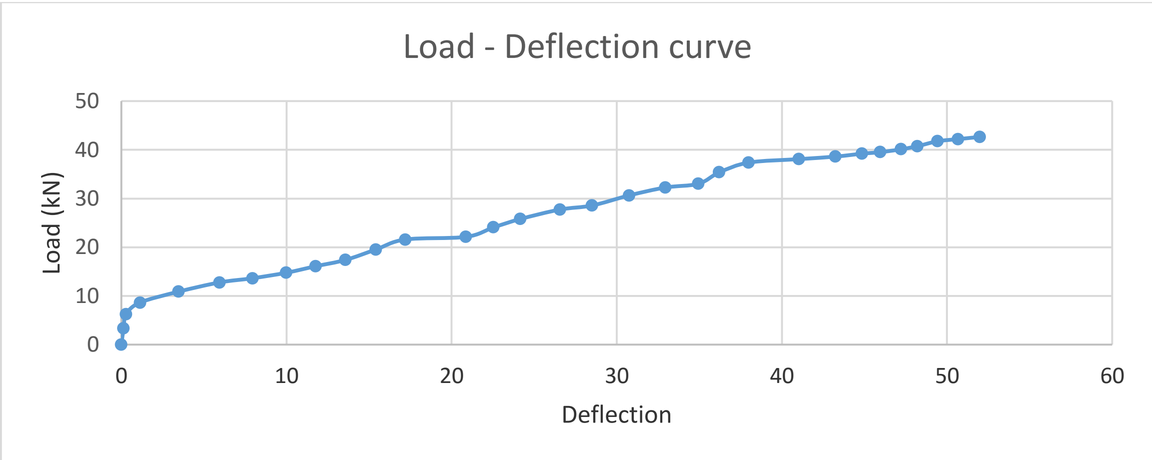


Figure 13: Load – Deflection Curve for Slab S3

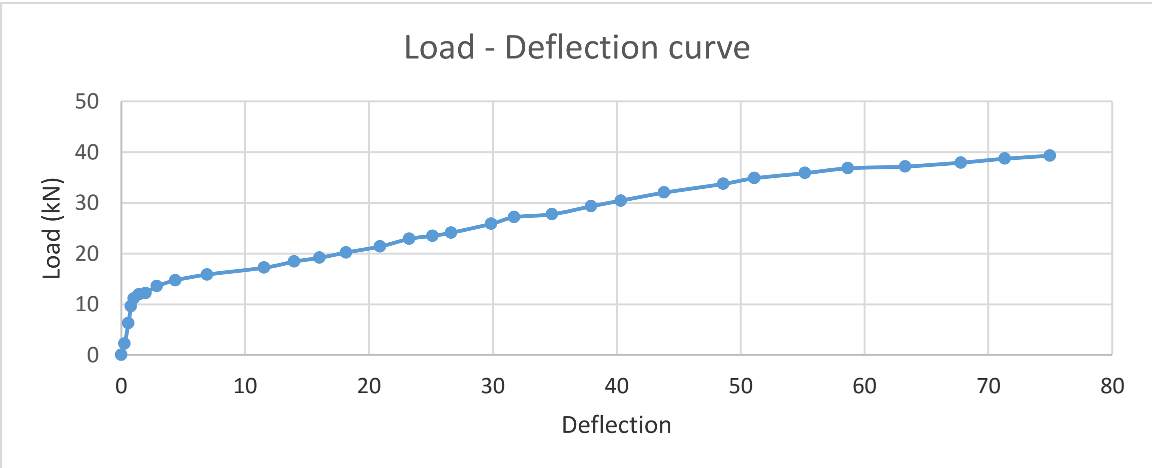


Figure 14: Load – Deflection Curve for Slab S4

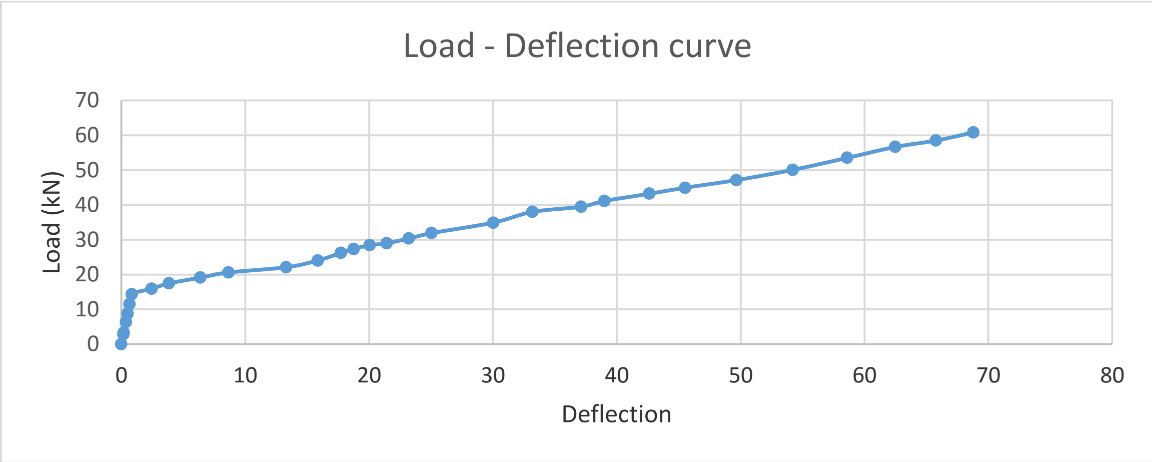


Figure 15: Load – Deflection Curve for Slab S5

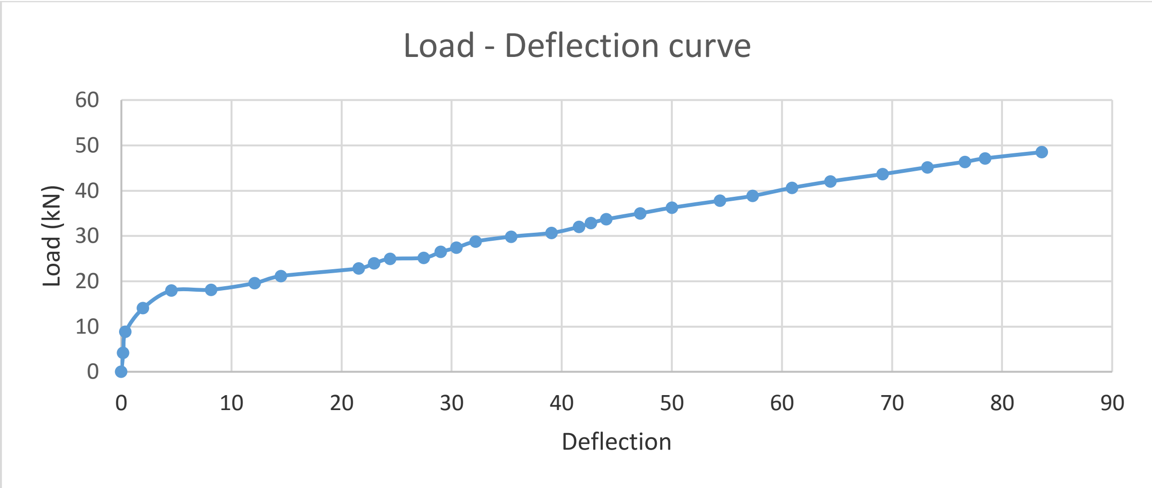


Figure 16: Load – Deflection Curve for Slab S6

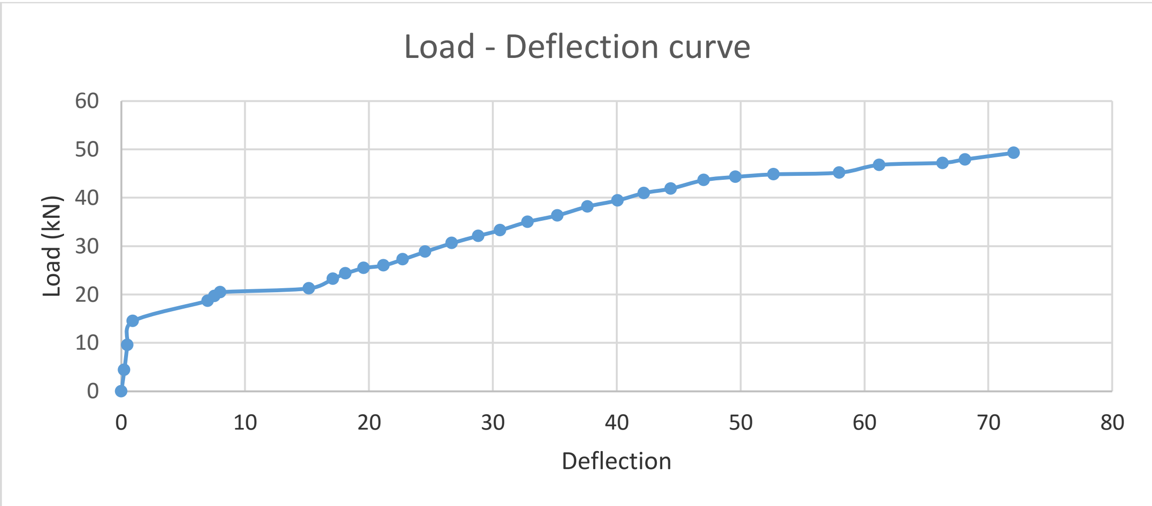


Figure 17: Load – Deflection Curve for Slab S7

3-3 The cracking and failure loads

To evaluate the enhancement percentage for each parameter Figure 18 and 19 are introduced where the vertical axis shows the percentage of improving the loading capacity (at crack and ultimate stages) from specimens reinforced.

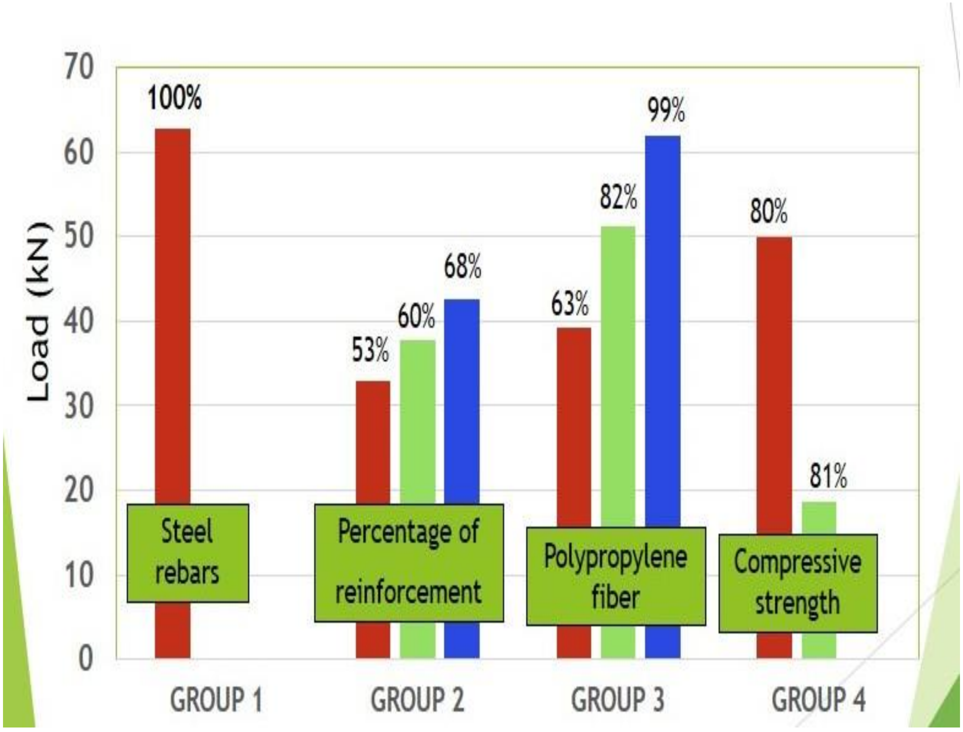


Figure 17: Cracking Load

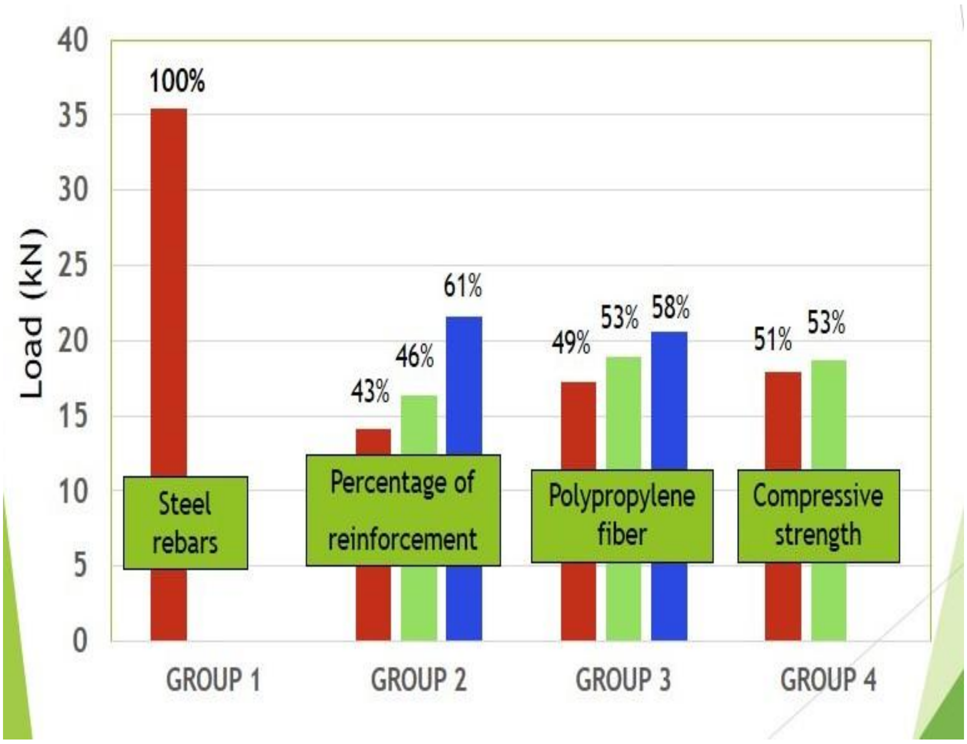


Figure 18: Ultimate Load

3-4 The deformed shapes

The deformed shapes of all the slabs were semi parabolic in shape, having maximum values of deflections at mid-span and zero at the two supports, the deflections value are different from slab to another depending on the studying parameters. In general the deflection values of BFRP-bars reinforced slab without enhancement were higher than the steel sample. The enhancing parameters improved the deflection values of slabs and pushed them to be closed to the steel sample deflection values. Figures from 19 to 21

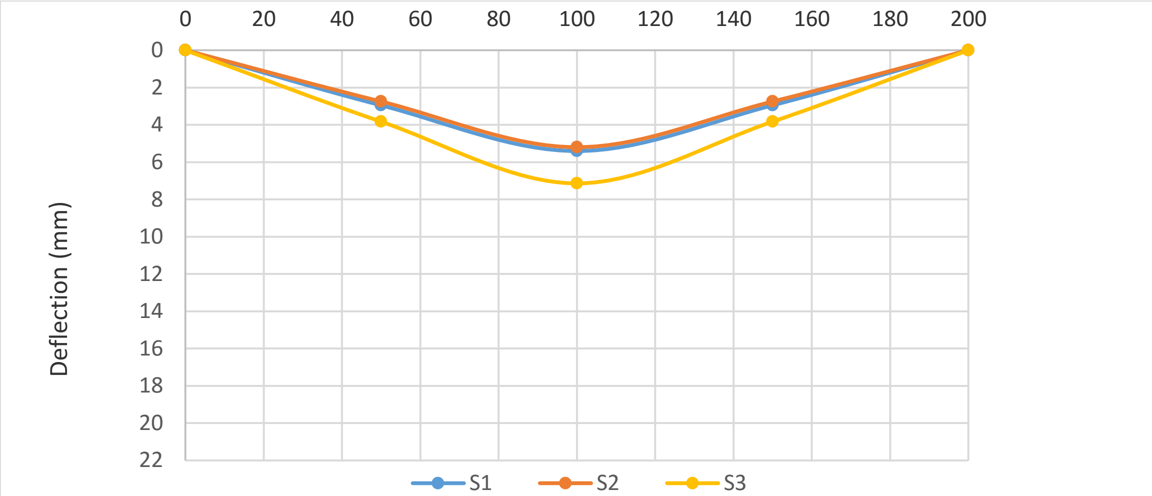


Figure 19: Effect of Area of Reinforcement on deformed Shapes of Slabs

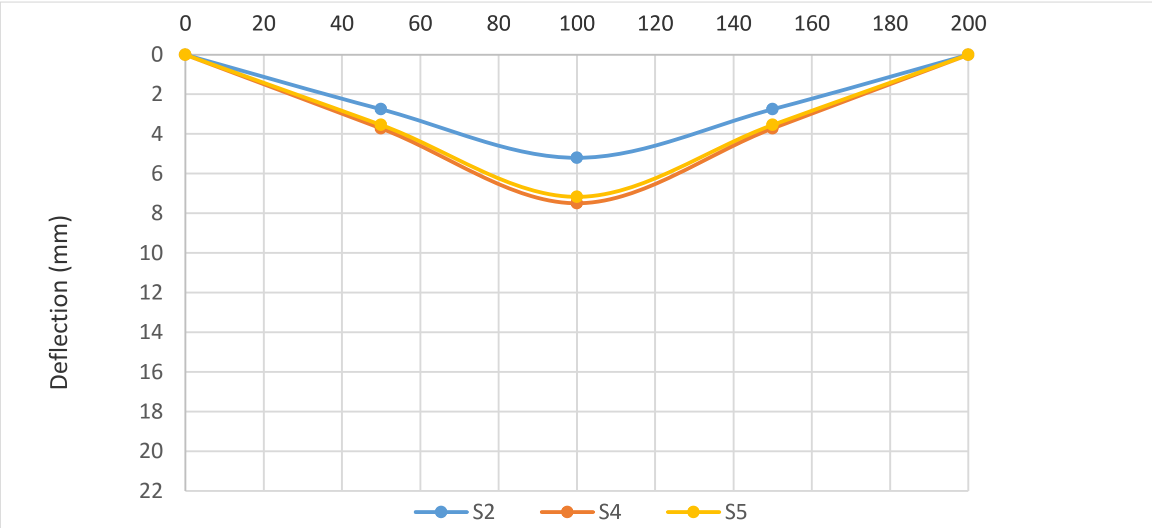


Figure 20: Effect of Polypropylene Fibers on deformed Shapes of Slabs

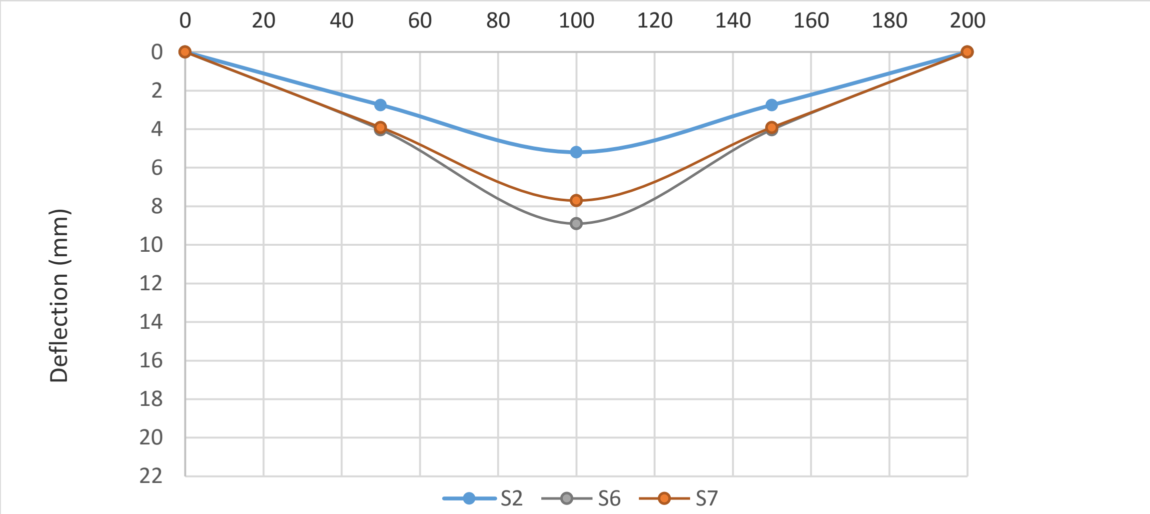


Figure 21: Effect of Polypropylene Fibers on deformed Shapes of Slabs

4. Conclusion

Seven slabs specimens were tested to evaluate the influence of using BFRP-bars instead of the traditional steel reinforcement. Several parameters were considered in this research such as reinforcement ratio, compressive strength and addition of the polypropylene fibers to the concrete mix. By analyzing the experimental results it is concluded that:-

1-The produced BFRP-bars have a relatively high average tensile strength of 1460 MPa, and modulus of elasticity of about 49 GPa, which is approximately 40 % of that of steel.

2- The bond strength of BFRP-bars having been approximately 78 % of that of steel bars. Adding polypropylene fibers to the concrete mix by amount of 7 kg/m^3 and increased the bond strength of BFRP-bars by about of 15% more than it for BFRP-bars of without polypropylene fibers and reached approximately 93 % of the bond strength of steel bars. The bond strength of the improved BFRP-bars reached 97 % of the bond strength of steel bars when using the polypropylene fibers by amount of 1 kg/m^3.

3- The stiffness of BFRP reinforced concrete slab was significantly lower than it for the steel reinforced slab with the same area of reinforcement of 339 mm2 (3 Ø12). Increasing the area of reinforcement of BFRP-bars from 339 mm2 to 565.5 mm2 (5 Ø 12) by about 165 %, improved the stiffness of the concrete slabs by 48%.

4-The cracking loads of the BFRP-reinforced concrete slabs was significantly lower than it for the steel reinforced concrete slabs with the same area of reinforcement because of the great difference in the stiffness between the BFRP-bars and steel, but the ultimate loads were significantly higher because the tensile strength of BFRP is higher than that of steel.

5- The specimens without polypropylene fibers showed wide cracks at failure. Adding the polypropylene fibers by amount of 1kg/m^3 improved the mechanical characteristics of the concrete mix which led to narrower and more uniformly distributed cracks, consequently the cracking loads and ultimate capacity increase than the specimens without polypropylene fibers, more improve of the behaviour of the slabs was achieved when changing the amount of the polypropylene fibers from 1 to 2 kg/m^3.

6- The specimens reinforced with0 3 Ø 12 (reinforcement ratio of 0.57 %) with had higher deflections and reinforcement strains and lower stiffness and cracking loads than the steel specimen reinforced with 3 Ø 12.

On the other hand, when samples reinforced with the largest reinforcement 5 Ø 10, adding the polypropylene fibers and increasing the compressive strength of the concrete, the results obtained were almost equivalent to the steel sample reinforced with 3 Ø 10.

5. Recommendations for future work

1- The BFRP-bars may be used as reinforcement for slabs subjected to aggressive environment since they are highly resistant to corrosion and can be manufactured with adequate quality control provided that all other disadvantages could be overcome. This can be achieved when further experimental studies are performed on slabs reinforced with BFRP-bar and polypropylene fibers to get more knowledge about the behavior of such slabs. This task became mandatory in this stage in order to reach comprehensive code recommendations to obtain a good idea about the appropriate combinations between BFRP-bars and polypropylene fibers which should be used in practical cases to obtain similar results as steel reinforcement.

2- Better quality of bars can be reached if the manufacturing of these bars are quality controlled in a specialized factory and not in small workshop. These bars should be helically wrapped with fibers to enhance their bond characteristics. This is in addition to adding polypropylene fibers to the concrete mix.

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