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Reinforcement of concrete with composite materials based on fiberglass

Ahmed Lamine BENZERGA [1], Mohamed AMIEUR [1] and Rachid RABEHI [1, *]

[1]*National School of Built and Ground Work Engineering, Laboratory of Public Works Transport and Environmental Engineering (LTPiTE), ENSTP, Alger, Algeria*

[*]*(rachid.rabehi@univ-djelfa.dz) Email of the corresponding author*

Abstract – Many existing constructions (old and new) have significant deficiencies in terms of load-bearing capacity which, in some cases, could jeopardize the safety of their users. Indeed, we can consider that these structures have arrived (or will arrive very soon) at the end of their useful life, hence the need to find technical and economic solutions to rehabilitate them in the most effective way possible. In the case of reinforced concrete bridges, very many suffer from an advanced state of degradation caused by prolonged exposure to an aggressive environment or even a continuous increase in use loads. In addition, for the old structures, the technical standards used for their design and dimensioning had to be modified from the date of their construction. Thus, certain structural elements in service no longer meet the performance requirements in terms of response to loads. Indeed, it is often less expensive to reinforce the structural elements of structures than to carry out a complete reconstruction, especially since following the evolution of technology, several methods of reinforcement remain available on the market and with prices more and more competitive, including that which consists of the external reinforcement of reinforced concrete elements with composite materials which, due to their strength/weight ratio and their resistance to external agents (non-corrodible product), have very interesting advantages if they are compared to steel whether it is used passively or actively (simple reinforcement or prestressed). In addition, these composite materials can be used both for shear and bending reinforcement for beams and for column containment. This work aims to use (FRP) Fiber Reinforced Plastics (materials generally formed of two main and distinct elements: the fiber "made from Glass" and the matrix "an epoxy resin which allows the transfer of loads between the fibers which improves the properties, in the long and short term"), to assess the influence of glass fibers on the general behavior of concrete, in particular on its resistance, its deformations and its ductility. The results obtained at the end of the cyclic loading tests of the specimens confirm the importance of the contribution that the confinement of the concrete specimens by FRP can bring in terms of resistance to compression and deformation observed following the realization of the static loading tests. However, these cyclic loading tests of the specimens show us the very considerable gain in the ability of the specimens to withstand loading-unloading cycles.

Keywords – Concrete, Composite Materials, Fiberglass, Compressive Strength, Deformation, Ductility

I. Introduction

He is often less expensive to reinforce the elements structures of the works than to carry out a complete reconstruction, especially since following the evolution of technology , several reinforcement methods remain available on the market and with increasingly competitive prices of which that which consists in strengthening external elements reinforced concrete with composite materials which , due to their strength / weight ratio and their resistance to external agents (non- corrodible product), have very interesting advantages compared to steel that he either used passively or actively (single frame or prestressing) [1]. Moreover, these composite materials can be used for both shear and bending reinforcement for beams than at the confinement of the columns. Plastics Fiber Reinforced (FRP) are materials formed usually two elements main and distinct: the fiber and the matrix. fibers are made from one of the following types: Carbon, Glass or Aramid. The matrix itself East a resin of epoxy and allows the transfer of charges between the fibers which improve the properties, in the long and short term, of the matrix and make it possible to reduce the effects of shrinkage and creep. Fibers have the advantage of the power to be very long in continuous form which is perfectly suitable for civil engineering applications. Like them can be placed in a or several directions inside the matrix [1]. FRPs are manufactured under various shapes (thin sheets, bars, profiles, etc.) each product suitable for a very specific use in the field of construction. Their properties such as that a high strength -to- weight ratio and a excellent resistance to electrochemical corrosion make these products of highly sought-after materials for cases of application structural. This demonstrates how much research are to be done in order to better to know their properties and favor their use in the field of construction.

II. Formulation

Materials used in this work are local and natural available on the market Algerian. Table 1 summarizes all materials used, and Tables 2 and 3 summarize lures physical and mechanical characteristics.

Table 1. Materials used.

Used materials	Nature	Kind
Cement (C)	Compound cement	CPJ 42.5N
Sand (S)	Alluvial	(0/5)
Natural gravel (N)	Crushed, limestone	(3/8) and (8/16)
Fiberglass (Fv)	Glass	-
Resin	-	2-component predosed kit form
Mixing water (E)	Potable water	-

Table 2. Physico-mechanical properties of aggregates.

Granular class / Physical property	Sand	Gravel	
	(0/5)	(3/8)	(8/16)
Apparent density (g/cm ^{3})	1.55	1.360	1.353
Absolute density (g/cm ^{3})	2.58	2.66	2.66
Fineness modulus	2.14	---	---
Sand equivalent (%)	79.27	---	---
L.A. coefficient (%)	---	23.54	27.78

Table 3. Chemical characteristics of fiberglass.

Constituents		**(%)**	**Photo**
Silica	SiO_2	53-54	
Alumina	Al_2O_3	14-14.5	
Lime	Cao	20-24	
Magnesia	Mg		
boron oxide	B_2O_3	6.5 -9	
Fluorine	F	0.0.7	
Iron oxide	Fe_2O_3	≤ 1	
titanium oxide	TiO_2		
sodium oxide	Na_2O	≤ 1	
Potassium oxide	K_2O		

Table 4. Characteristics of the polymer matrix (the resin).

Features	**Results**	**Units**	**Photo**
Density (iso758)	1.1 ± 0.05	-	 
Viscosity (NFT76-102)	11000	MPa.s at 25°C	
Practical duration of use (NFP18 810)	1H15mn	Hours	
Curing time at 20°C and 65%RH			
Ø Excluding poise:	6	Hours	
Ø Hard :	16		
Compressive strength (NA427)	>70	MPa	
Bending strength (NA234)	>25	MPa	
Adherence to concrete	>3	MPa	

Formulation of Concrete

The Dreux Gorisse method was used for the development of the concrete formulation. This method is based on the use of curves reference granular, allowing to approach by calculation or by the geometrical construction the optimal proportions of the various granular fractions.

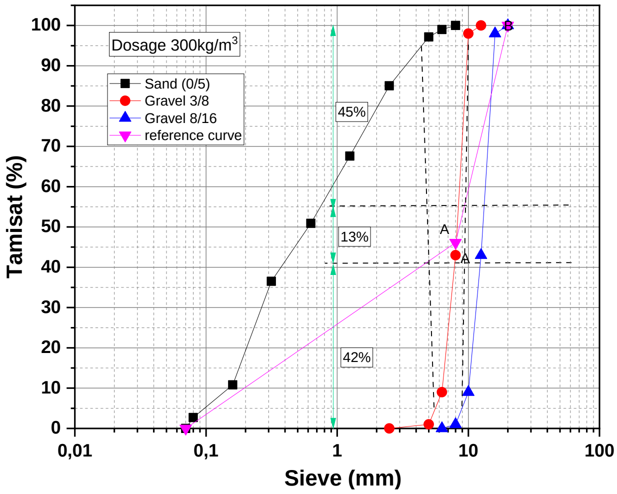


Figure 1. Curves particle size of the concrete aggregates dosed at (300kg/m^3).

Table 5. Dosage of the composition for 1 m^3 Concrete.

Composition	**Unit**	**Dosage**
Cement	Kg /m^3	300
3/8 gravel	Kg /m^3	192,379
Gravel 8/16	Kg /m^3	1000.365
Sand 0/5	Kg /m^3	706,303
Water	L/m^3	156
G/S	/	1.69
E/C	/	0.5

III. RESULTS OF EXPERIMENTAL TESTS

We have proceeded to the comparison of the compressive strength measurements and the deformations of the specimens reinforced with one ply, two ply or three plies of fiberglass with those of the unreinforced specimens.

Load test results static are summarized below:

Figure 1. Concrete specimens without reinforcement after crushing.

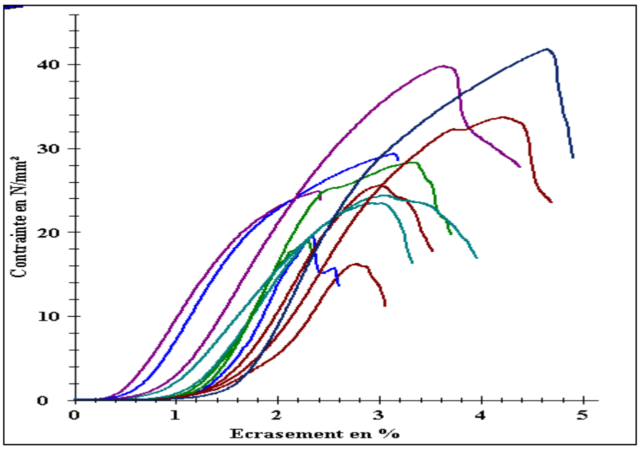
Figure 2. Fracture surfaces of concrete specimens confined by 1-ply FRP.

Figure 3. Fracture surfaces of concrete specimens confined by 2-ply FRP.

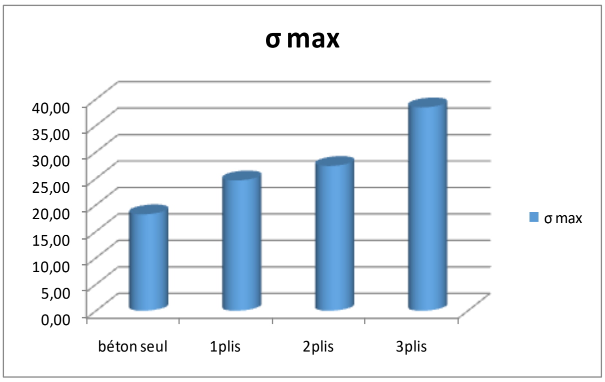
Figure 4. Fracture surfaces of concrete specimens confined by 3-ply FRP.

Table 6. Summary of crushing results for concrete specimens

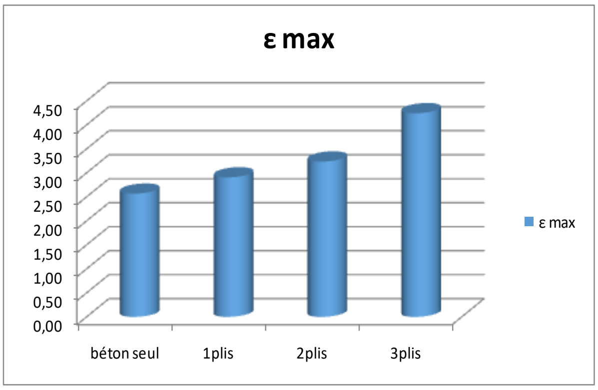
	Age (Days)	σ_{max}	ε_{max}	$\sigma_{rupture}$	$\varepsilon_{rupture}$	Gain σ	Gain ε
Concrecte	35	18,23	2,57	18,00	2,63	-	-
1pli	35	24,62	2,91	24,97	3,12	35,10%	18,48%
2plis	35	27,36	3,24	27,10	3,67	50,13%	39,37%
3plis	35	38,43	4,24	28,10	4,67	110,84%	77,22%



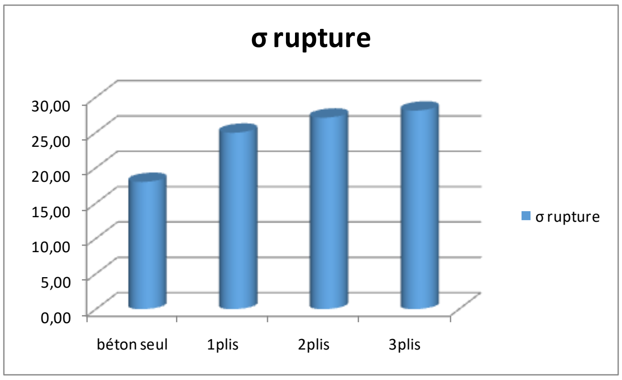
Graph 1. Global curve of σ-ε for all the tests on confined concrete specimens.



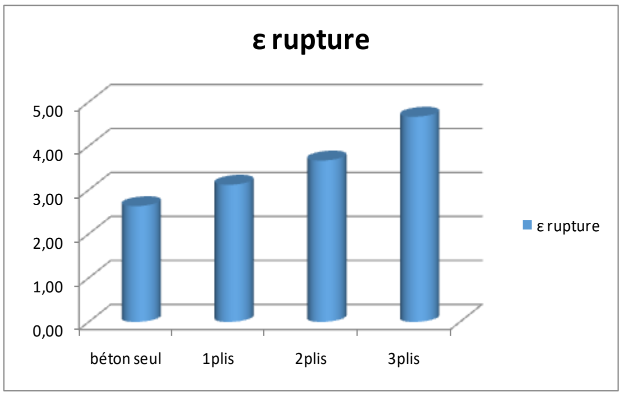
Histogram 1. Comparison of stress values maximum.



Histogram 2. Comparison of strain values maximum.



Histogram 3. Comparison of breaking stress values.



Histogram 4. Comparison of fracture strain values

Reading all of these results allows us to perform analysis following:

The curves are characterized for all the specimens (confined by PRFV or not) by a linear phase elastic followed by a curvature representing the plastic phase [2].

development phase of concrete microcracking results in a progressive curvature of the curve until the achievement of the constraint maximum σmax _ corresponding to a certain deformation value ε.

By imposing slower strain increments, we get a curve decreasing corresponding to the accentuation of the rupture, i.e. to the development of the rupture surfaces and a cracking generalized.

Table 7. gives a comparison of results obtained in depending on the number of fiberglass plies. This table highlights shows a very significant gain in terms of resistance maximum and deformation [3].

Taking as a reference the results crushing of specimens without confinement by FRP, we obtain a gain in compressive strength of 35.10% for reinforcement with 1 ply of fiberglass, 50.13 % for 2 ply and 110.84% for 3 plies.

In the same way we obtain a gain in deformation of 18.48% for 1 ply, 39.37% for 2 ply and 77.22% for 3 plies [4].

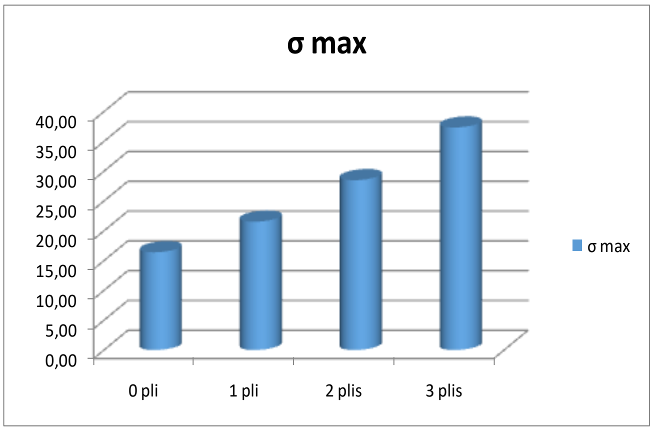
Load test results static are summarized below:

Table 7. Results according to number of folds.

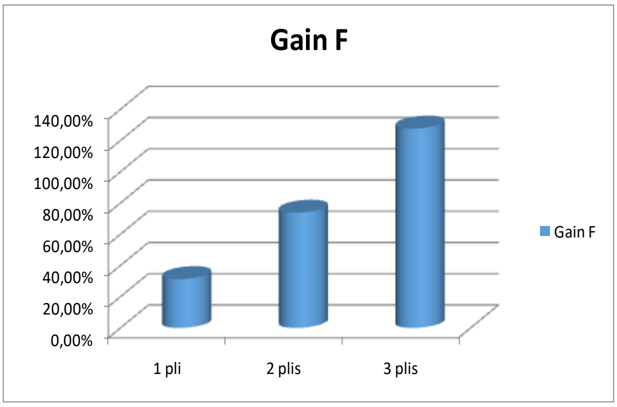
série	éprouvettes	Nbre cycle	Force de Rupture	Allongement
			N /mm2	%
Béton seul	$BR0P_1$	49	18,6	1,65
	$BR0P_2$	47	14,2	1,61
1 plis	$BR1P_1$	67	21,05	2,8
	$BR1P_2$	73	22	2,81
2 plis	$BR2P_1$	92	28	3,95
	$BR2P_2$	90	29	4
3 plis	$BR3P_1$	110	39	5,75
	$BR3P_2$	118	34	4,6
	$BR3P_3$	113	39	5,25

Table 8. Comparison of mean results.

Nbre de plis	σ_{max}	N_{cycle}	ε_{max}	Gain F	Gain ε	Gain N
0 pli	16,40	48	1,63	-		-
1 pli	21,53	70	2,81	31,25%	72,09%	45,83%
2 plis	28,50	91	3,98	73,78%	143,87%	89,58%
3 plis	37,33	114	5,20	127,64%	219,02%	136,81%

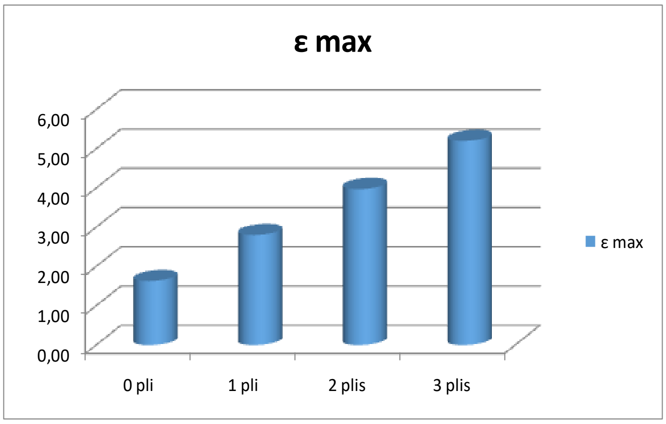


Histogram 5. Evolution of stresses in depending on the number of plies of the FRP.

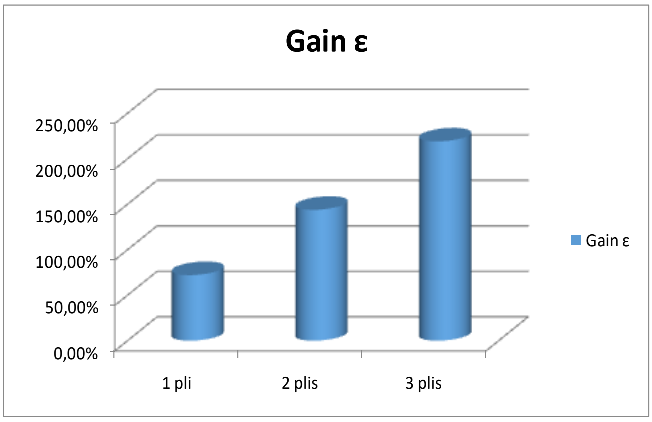


Histogram 6. Stress Gain in depending on the number of PRFV plies.

The confinement of the specimens by PRFV allows us to increase considerably the breaking stress under loading cycle of concrete [5]. For a concrete with a compressive strength of around 16N/mm² containment with a PRFV of only one crease we get a resistance of the order of 21.5N/mm² and for a 2- ply GRP the resistance East increased to 28.5N/mm² and up to over 37N/mm² with 3- ply GRP which corresponds respectively to 31.25%, 73.78% and 127.64% gain in compressive strength [5].

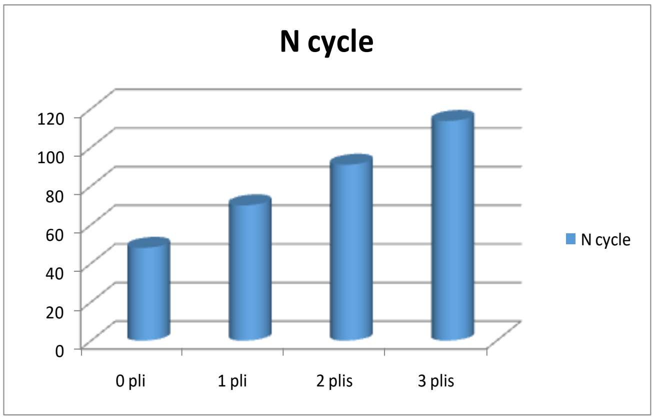


Histogram 7. Evolution of concrete deformation in ply count function of the CFRP.

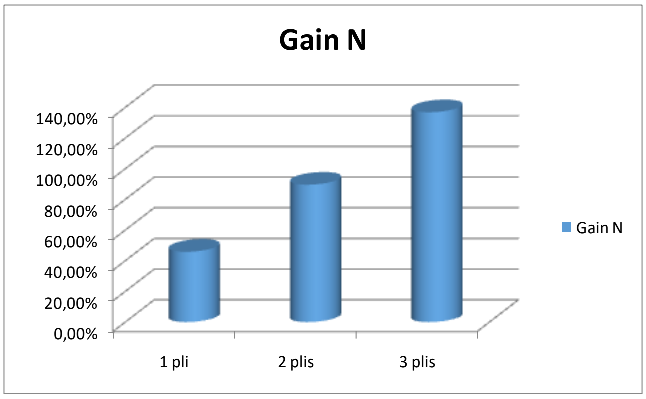


Histogram 8. Strain gain in depending on the number of plies of the FRP.

He is the same for the deformation maximum under load cyclic or we get a very significant increase in deformation in depending on the number of plies. Maximum elongation increases from 1.63mm for unconfined concrete to 2.81mm for 1-ply FRP confinement, 3.98mm for 2- ply and 5.20mm for 3- ply which correspond respectively to gains in deformation terms of 72.09%, 143.87% and 219.02%.



Histogram 9. Evolution of the number of cycles as a function of the number of PRFV plies.



Histogram 10. Gain in number of cycles according to the number of folds of the PRFV.

In terms of the number of loading-unloading cycles we find as this hint increases from 48 cycles for non-confined concrete to 70 cycles for 1- ply GRP confined concrete, 91 cycles for 2- ply GRP and 114 cycles for 3- ply which correspond respectively to gains in number of load-unload cycles of 45.83%, 89.58% and 136.81%.[5]

IV. CONCLUSION

Important findings following are taken from this research:

- The gain in terms of concrete strength by reinforcement with a fiberglass-based composite material is very significant and depends on the number of plies. The gain is around 37% for 1 trick, 95% for 2 tricks and 150%.
- The gain in strength is proportional to the number of fiberglass plies.
- In terms of axial deformation, a gain proportional to the number of plies was observed for the use of fiberglass. This gain is 150% for 1 trick, 162.5% for 2 tricks and 172.5% for 3 tricks.
- A decrease in the radial deformation was observed in all cases of reinforcement of the specimens. This decrease is proportional to the number of plies 50%, 45% and 42.5% for 1, 2 and 3 plies of fiberglass respectively.

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