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NUMERICAL SIMULATION OF COMPOSITE CASTOR OIL POLIURETHANE WITH SISAL FIBER TO STRENGTHEN CONCRETE SLABS

Lauren K. S. Gonçalves*, Leila A. C. Motta*, Luan S. M. Gonçalves*, Mariana C. S. Vieira*

*Universidade Federal de Uberlândia
Faculdade de Engenharia Civil
laurenkaroline@feciv.ufu.br

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Summary: *In construction, the study of composites reinforced with natural fibers is important to discovery new techniques and materials, with lower waste and costs, using renewable and biodegradable materials. In this paper, numerical simulation have been performed by using Finite Element Method, to analyze the efficiency of natural fibers reinforced polymeric composite for strengthen concrete structures. The matrix and fiber of this composite were castor oil polyurethane and sisal unidirectional distributed. Strengthening with natural composite increased strength and stiffness of slab. However, compared to the structure reinforced with composite of epoxy and carbon fiber, the performance was lower than when applied reinforcements with the same thickness. But the performance may be equivalent by increasing thickness of reinforcement with natural fiber.*

1 INTRODUCTION

The concrete, wood and steel structures are subject to flaws in projects, implementation and modification of the type of occupation, requiring strengthening of structures. Currently, the composites have proven to be effective in strengthening concrete structures because of good strength-to-weight ratio and ease of application and use. Composite have remarkable structural and constructive qualities compared to traditional materials. They present anisotropic behavior with some advantages, like low density, high mechanical properties, manipulation of stiffness, static resistance, fatigue, corrosion and abrasion [4, 5, 6, 7].

The polymeric composites reinforced with carbon fiber are used for strengthening and rehabilitation of concrete structures, however they are costly. Researchers have been developing materials, in order to find an alternative solution to replace the PRFC with lower cost and similar performance.

The purpose of this work is to analyze the efficiency of natural fibers reinforced polymeric composite for strengthening concrete structures using numerical simulation to test the material. The composite materials tested were sisal fiber reinforced castor oil polyurethane matrix and carbon fiber reinforced epoxy resin.

2 NUMERICAL SIMULATIONS

Nowadays, the finite element method (FEM) is a digital approximation technique appropriate to analyze the structural behavior and solve the problems [3]. The composites for strengthen concrete slab were numerically simulated using ANSYS® software. Different element types of the program were selected for each model of reinforced slab (concrete, steel and wood).

At ANSYS® is necessary to determine the properties of materials, geometrical characteristics, applied load and support conditions. The reinforcing steel bars, attending Brazilian Standard NBR 7480 (CA 60), has the following properties [2]:

- Elastic modulus: Es = 21000 kN/cm²;
- Diameter: 5.0 mm;
- Cross-sectional area: 1.963×10^{-5} m²;
- Moment of inertia: 3.068×10^{-11} m^4;
- ANSYS® Element type: BEAM3 [1].

The concrete properties:

- Compressive strength: 25.0 MPa.
- Elastic modulus: 2380 kN/cm²;
- Poisson's ratio: 0.20;
- ANSYS® Element type: SOLID45 [1].

The composite reinforced with natural fiber has the following characteristics [8]:

- Base: sisal fiber reinforced castor oil polyurethane matrix (PRFSisal);
- Ribbon width: 10.0 cm;
- Ribbon thickness: 3.0 mm;
- Elastic modulus: 2219 kN/cm²;
- Tensile strength: 14.75×10^7 N/m²;
- Poisson's ratio: 0.27 (adopted);
- Maximum strain: $\varepsilon \leq 3\%$;
- ANSYS® Element type: SHELL63 [1].

The PRFC were the Sika Carbodur, commercial, considered with the following characteristics [3]:

- Base: carbon fiber reinforced epoxy matrix (PRFC);
- Ribbon width: 10.0 cm;
- Ribbon thickness: 1.2 mm;
- Elastic modulus: 15500 kN/cm²;
- Tensile strength: 2.4×10^9 N/m²;
- Poisson's ratio: 0.27 (adopted);
- Maximum strain: $\varepsilon \leq 1.9\%$;
- ANSYS® Element type: SHELL63 [1].

The mechanical boundary conditions were a square slab supported on four sides also behaving as two-way slab, with dimensions of 5.0 m × 5.0 m and thickness of 10.0 cm. The steels bars were 10.0 cm interspaced at the longitudinal and transverse directions. It was adopted concrete cover of 2.0 cm and distributed load of 15000 N/m², following the dimensioning by [3], illustrated in Figure 1.

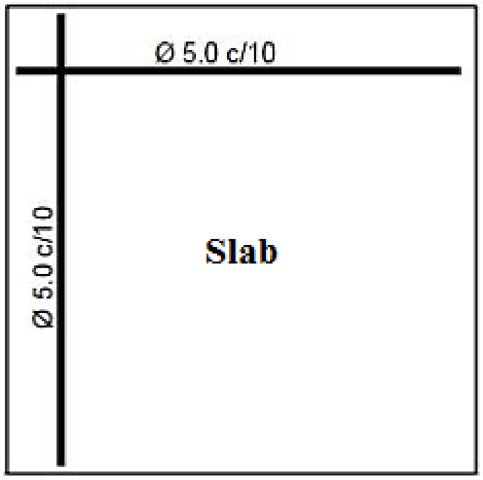

Figure 1 - Square slab supported on four sides [3]

The efficiency of strengthening with natural composite were analyzed and compared using 15 tracks of strengthening in each direction with an area of 15 m² and thickness of 3 mm for the PRFSisal and PRFC, showed by Figure 2.

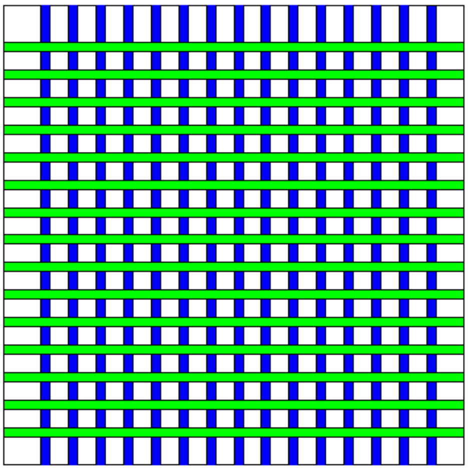
Figure 2 - Tracks of strengthen in the slab

3 RESULTS

It were determined the z-axis deflection of the structure (Figure 3), the normal stress (Figure 4 and 5) and the Von Mises stress (Figure 6). The deflection and the stresses allow evaluating the stiffness of the structure and the strength of the slabs, respectively. The Figure 6 shows the substantial reduction of the deflection with different composites for strengthening concrete slabs.

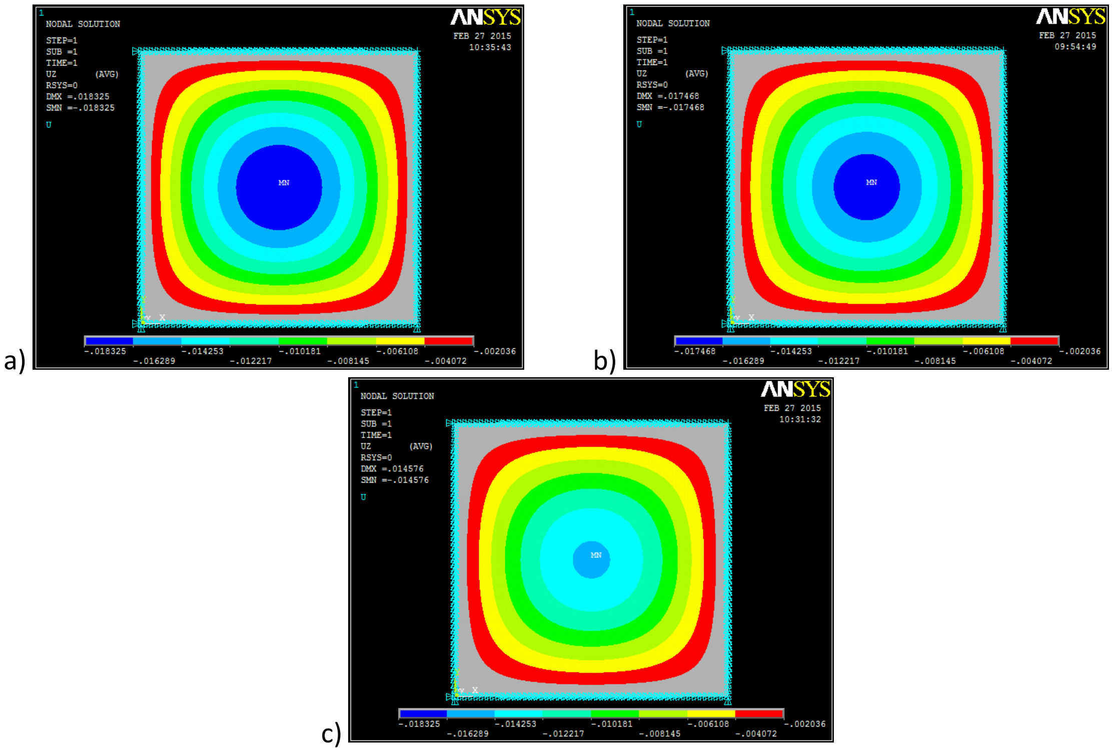

Figure 3 – Deflection of the slab (m): a) without reinforcements; b) natural fiber strengthening; c) carbon fiber strengthening

The behavior at the bottom of structure showed that the strengthened slab presented lower normal stress, illustrated in Figure 4.

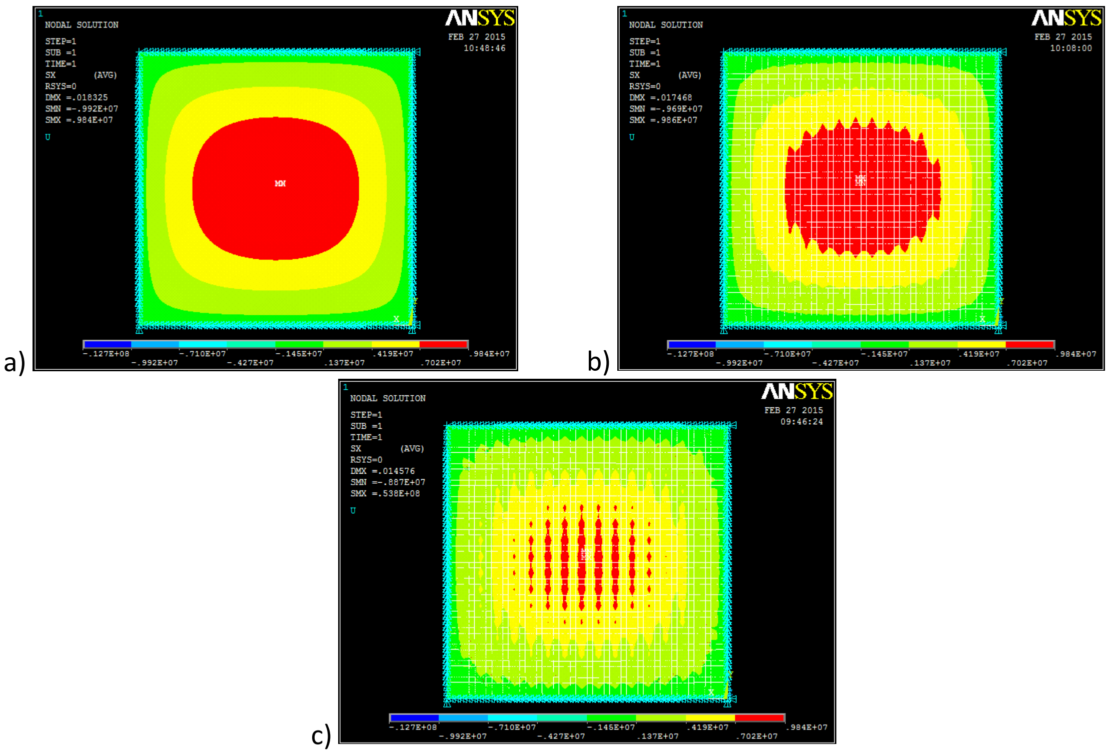

Figure 4 - Normal stress at the bottom of structure (N/m²): a) without reinforcements; b) natural fiber strengthening; c) carbon fiber strengthening

The Figure 5 shows the behavior of the structure at the top of the slab.

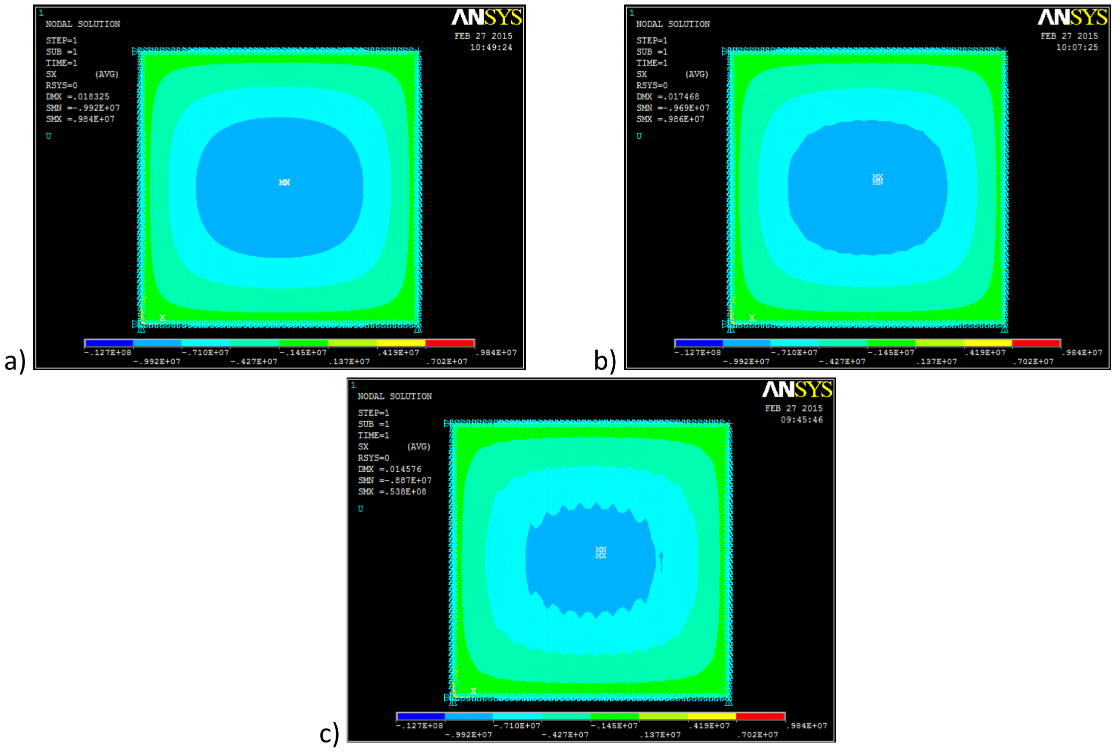

Figure 5 - Normal stress at the top of structure (N/m²): a) without reinforcements; b) natural fiber strengthening; c) carbon fiber strengthening

The results of Von Mises stresses were shown in the Figure 6.

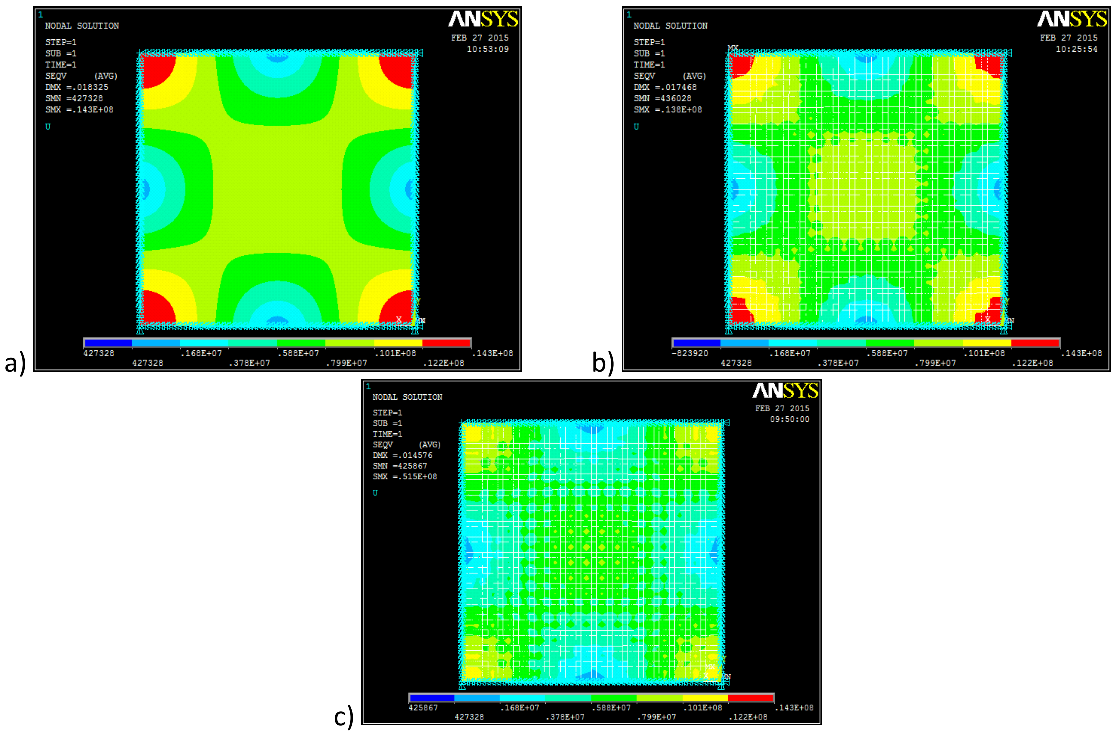

Figure 6 - Von Mises stresses at the structure (N/m²): a) without reinforcements; b) natural fiber strengthening; c) carbon fiber strengthening

It was observed that at the top the decrease of normal stress was lower than at the bottom of the slab. It is possible to notice the decrease of Von Mises stress with the introduction of different composites for strengthening concrete slabs, thereby the behavior is similar of the one observed in normal stress.

The nodes 1351 and 9154 were selected of the bottom and the top, respectively, at ANSYS® simulation. It was obtained the results for the slab with and without composites strengthening, showed in Table 1 and Figure 7, considering the same cross sectional area and thickness for PRFSisal and PRFC.

Slab	**Thickness** (mm)	**Maximum strain** (mm)	**Normal stress**		**Von Mises stress**	
			Bottom z=0 (x10^6 N/m²)	Top z=0,1 m (x10^6 N/m²)	Bottom z=0 (x10^6 N/m²)	Top z=0,1 m (x10^6 N/m²)
No reinforcements	-	18.26	9.81	9.89	9.81	9.88
PRFSisal	3	17.40	8.88	9.53	8.90	9.43
PRFC	3	14.52	6.32	8.39	6.35	8.15

Table 1 – Properties of the slab without and with tracks strengthening by thickness of 3 mm

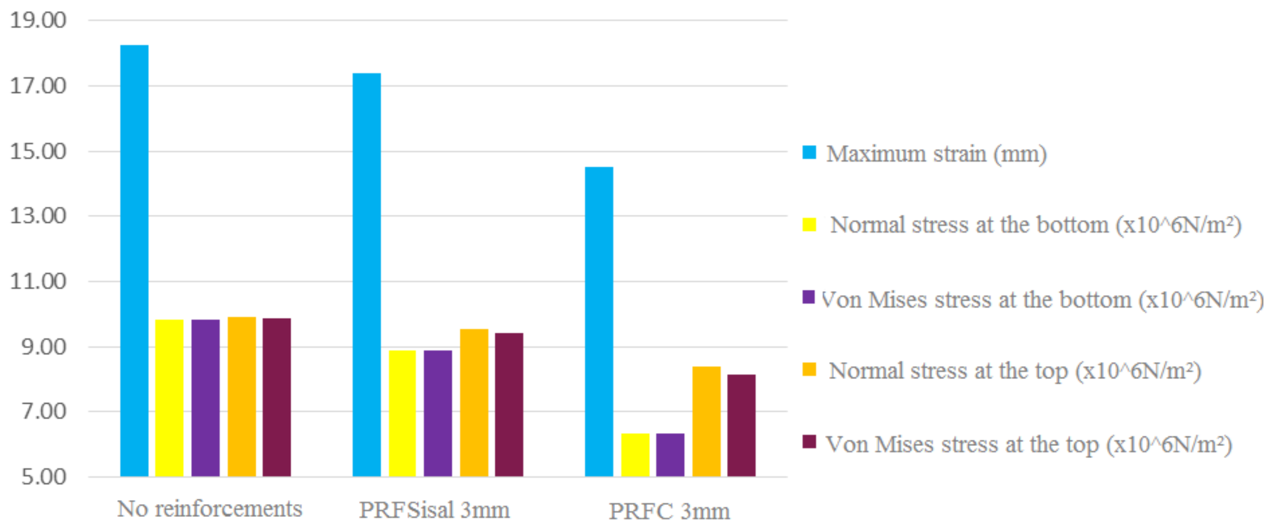

Figure 7 – Behavior of the slab with and without the tracks strengthening by thickness of 3 mm

Analyzing the results, the PRFSisal for strengthen slabs showed lower stress and strain compared with slabs without reinforcements, therefore higher strength and stiffness. However, the PRFC showed better properties than the PRFSisal, mainly because elastic modulus is approximately 7 times bigger than PRFSisal.

It was observed that the strengthening with castor oil polyurethane composite reinforced with sisal fiber with thickness of 8.5 mm is equivalent to the tension and maximum strain of PRFC Sika Carbodur marketed with thickness of 1.2 mm (Table 2 and Figure 8).

Laje	Maximum strain (mm)	Normal stress ($x10^6$ N/m²)	Von Mises stress ($x10^6$ N/m²)
No reinforcements	18.26	9.81	9.81
PRFSisal 3mm	17.40	8.88	8.90
PRFSisal 5mm	16.93	8.41	8.44
PRFSisal 8mm	16.32	7.84	7.87
PRFSisal 8.5mm	16.23	7.75	7.79
PRFC 1.2mm	16.26	7.78	7.81

Table 2 – Results for slabs with tracks strengthening of diferents thickness

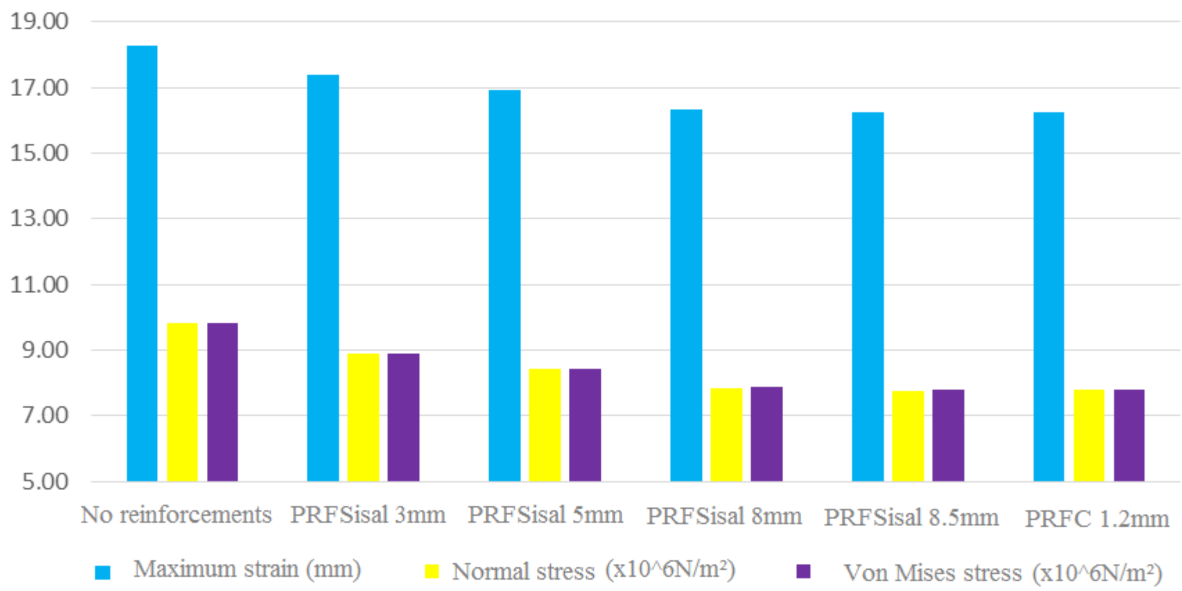

Figure 8 – The PRFSisal compared with PRFC commercial

4 CONCLUSIONS

The numerical simulations realized using ANSYS® presented good results for PRFC and PRFSisal used for strengthening concrete slabs, with emphasis on the lower stress and increased strength of the structure.

The results showed the increase of stiffness and strength with the variance of the thickness of the tracks of strengthening in the slab. However, compared to the structure reinforced with composite epoxy and carbon fiber, the performance was lower than when applied reinforcements with the same thickness. Though the performance may be similar by increasing thickness of reinforcement with natural fiber. The PRFSisal can be considered a viable alternative from the environmental point of view, since the resin and the fiber are biodegradable materials. Therefore, it is necessary to check the feasibility of application, thermal performance, cost and durability.

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