# Development and Characterization of Green Composites for Social Housing

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**Abstract.** Civil construction is one of the sectors of society that cause the most environmental impacts. The high consumption of natural resources, emission of carbon dioxide in the manufacture of industrialized materials, changes in soil, worsening of heat islands, waste production and water consumption. Therefore, the search for sustainable materials is gaining more prominence. Thus, a solution found is the use of composites reinforced with vegetable fibers and biodegradable matrix, called biocomposites. In addition to their sustainable character, vegetable fibers are low specific weight, abundance, low cost, and non-toxicity. The present research aims to develop and characterize 100% vegetable composites, using jute fiber fabric embedded in a liquid castor-based polyurethane matrix for application as wall and roof elements of social housing. These plates, in turn, are produced by the compression molding process, where layers of fabric and matrix are interspersed and compressed. The specimens produced with 40% fiber were tested under bending according to the ASTM D790 standards to check mechanical properties. The specimens were made in three directions (0°, 45° and 90°) to analyze the differences in response in each case. As a result, for the main direction the flexural strength reached 37.2 MPa, while the lowest result occurred in the 45° direction with a resistance of 16.9 MPa.

**Keywords:** Composite Materials, Biocomposites, Vegetable fibers.

## 1 Introduction

Construction professionals and the public are constantly increasing their awareness of the causes and worsening effects of climate change, waste increase and natural resources reduction. Therefore, the environmental impact caused by the AEC industry (Architecture, Engineering and Construction) becomes one of the main issues yet to be discussed, since it is the one responsible for most of these problems. Furthermore, the search for more sustainable materials with good mechanical properties is necessary to modify the production method of civil construction maintaining productivity and reducing the ecological footprint.

Civil construction is one of the sectors of society bearing abundance of environmentally harmful activities. The high consumption of natural resources, such as carbon dioxide emissions in the manufacture of industrialized materials, changes in soil and vegetation during land occupation, worsening of heat islands, increased electricity costs, waste production, consumption of water, among others. In the United States, buildings consume about 36% of the total energy available in the country, 30% of its raw materials and 12% of its water [1]. The waste production in both construction and demolition areas constitute a third of the solid waste generated in Europe, a total of more than 800 million tons generated per year [2]. In this sense, an analysis of traditional building materials and their direct and indirect impacts on waste production and resource consumption is necessary.

It appears then that the choice of a solid construction material cannot depend only on its load capacity and cost. Other material properties that should be considered are, among other aspects: durability, resistance to water vapor diffusion, temperature, and fire. It is necessary for the selected materials not to pose a risk to health, safety, and the environment [3]. Therefore, the best way to conserve the environment is through renewable and non-toxic natural materials, and every effort must be made to make them competitive [4]. Thus, this research for new materials has led the AEC industry to turn its eyes to the use of natural resources. This has made the interest in composites reinforced with natural fibers to grow, since these are presented as a more sustainable alternative, which can be processed with less energy consumption.

The replacement of conventional and artificial materials by natural fiber composites contributes to the creation of a sustainable economy [4]. In many parts around the world, in addition to agricultural purposes, different parts of plants and fruits from many crops have been shown to be viable sources of raw material for industrial purposes [5]. Vegetable fibers can be taken from these raw materials, providing significant reinforcement for resins and concrete when designing structural elements. Fibers of plant origin, which will be the object of study in this work, present abundance, greater availability than synthetic fibers and sustainability [6,7]. Furthermore, they are cheaper, pose no health risks and, finally, provide a solution to environmental pollution, finding new uses for agricultural waste [5].

Another big problem to be analyzed is the housing shortage. Due to severe shortages of essential building materials, coupled with low incomes, unemployment and an increase in population growth, millions of people in many developing countries lack adequate shelter. Providing decent social housing for the masses remains a real challenge for everyone associated with the planning and execution of various housing schemes [4]. In several cities, the housing of more than half of the urban population is restricted to slums with little to no access to basic needs such as water and basic sanitation. This reality mainly affects so-called developing countries, such as Brazil [8]. Getúlio Vargas Foundation and the Brazilian Association of Real Estate Developers emphasize that around 7.77 million housing units would be needed to meet the country's demand [9].

In this sense, this work proposes to evaluate the feasibility of using fibers and plant matrices as materials for the manufacture of components for social housing with low environmental impact, economically viable and that meet the immediate needs of the population.

# 2 Materials and methods

## 2.1 Fibers

To produce the plates, was chosen for the use of jute fabric, supplied by *Armazém da Juta* with fibers originating in the northern region of Brazil. This choice was made based on the studies by Wambua et al. [10] who showed that this type of fiber presents good responses when subjected to bending, which is the main type of loading expected. Furthermore, jute fabrics are readily available in the market at an affordable price.

## 2.2 Matrix

The main factors to be considered when choosing materials to produce a composite are stiffness and strength for structural applications [11]. For the manufacture of the plates, we chose to use Imperveg AGT 1315 resin, which is made from vegetable polyurethane derived from castor oil and is in accordance with the work's premise of using natural materials. It is made up of two components: component A being a prepolymer and component B being the polyol. Among the advantages cited by the manufacturer are high durability, great resistance to ultraviolet rays, impermeability to liquids and gases, good adhesion and negligible volumetric shrinkage after curing [12].

## 2.3 Preparation of specimens

To manufacture the plates, it is necessary to initially enumerate the materials used: vegetable resin described previously; silicone spray; steel shape; Jute fiber fabric. The jute fabric is composed of 1mm threads evenly distributed at 3 mm in the warp (length), which will be considered the main one, by 5 mm in the weft (width). The fabric is cut into rectangular pieces measuring 15x20 cm, with an average weight of five grams.

The manufacturing steps consist of applying silicone in the steel mold to prevent the composite from sticking to the mold 1(a). After that, a resin solution of components A and B in the proportion of 1:1.5 is prepared and poured (Fig. 1b). The resin and jute layers are arranged so that the fibers are embedded in the resin (c) and (d). Once this is done, the mold receives its lid (e) and is pressed with fastening clips (f), in order to reduce the amount of voids. No special control of the pressure was carried out, as the intention is to develop a simple and easy to fabricate material. In Figure 1, it is possible to observe the stages of manufacturing the plates.

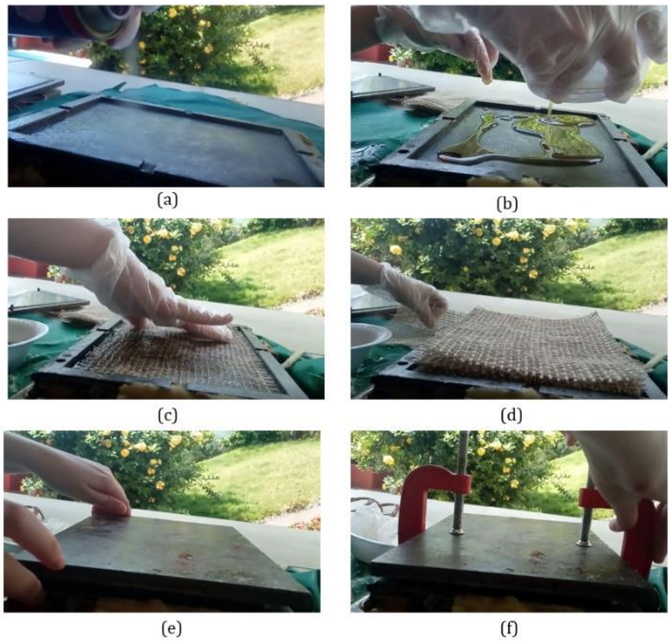



Figure 1 - Manufacturing steps for fence plates.

For this study, laminated boards with 40% fiber by weight were manufactured. Ten layers of jute fabric, with an average weight of 5 grams each, were used, resulting in fifty grams of fiber per plate. The fiber volume was subdivided into 33.0%±2% of this volume in the warp direction and 11.0%±2% in the weft direction in each specimen with dimensions 150x10mm and thickness of 6.5 ±0.5mm. The specimens were cut in three directions: 0° (parallel to the fiber warp), 45° and 90° (parallel to fiber weft). Figure 2 presents these specimens and their respective directions.

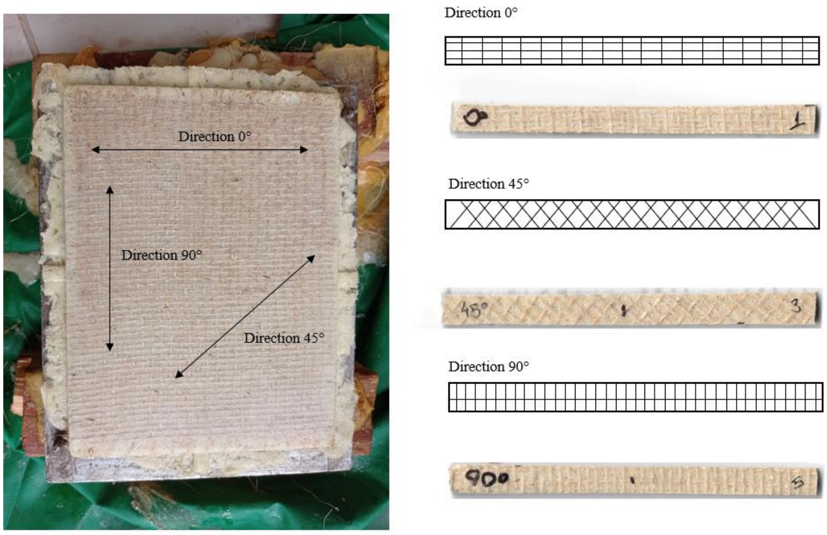



Figure 2 - Manufacturing steps for fence plates.

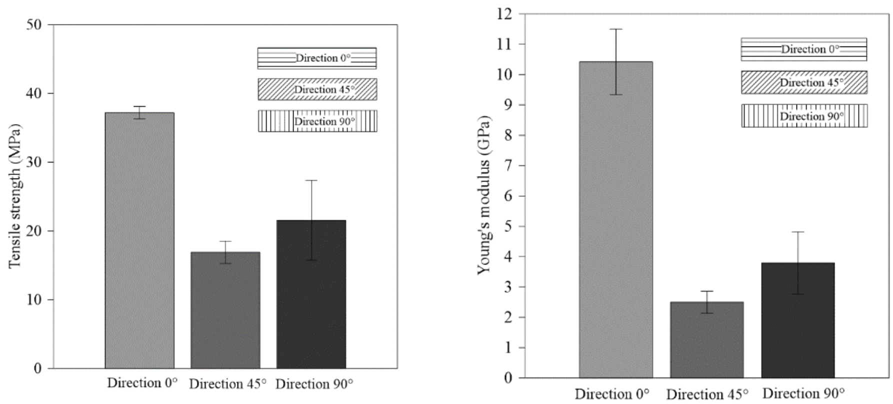
## 2.4 Testing methods

The flexural tests of the sealing plates followed the standards of the American Society for Testing and Materials (ASTM), following the procedure ASTM D790 - Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials [13]. The specimens were made in the three directions (0°, 45° and 90°). Its dimensions were 150x10mm, with a thickness of 6.50±0.50mm.

The test equipment assembling starts with the connection of the 2.5kN load cell to the 810 - 250 Material Test System testing machine. Then, support rollers are positioned at 100 mm from each other and 25 mm from the edges of the specimen. As for the degrees of freedom of the system, the support rollers have shown freedom of movement in the horizontal direction, allowing the test to occur without the generation of normal efforts on the part, at a speed of 2.65 mm/min, with a displacement limit of 20.0 mm.

## 2.5 Analysis

The plates were submitted to bending tests with monotonic loading. Tests were carried out on 15 specimens, five for each studied direction, with maximum deformation limited to 20 mm. Analyzing the flexural strength (a) and modulus of elasticity (b) graph of Figure 3, it appears that, as expected, the best results are obtained when the fiber is disposed in the longitudinal direction of the material, since it is in this position that it best resists the requested efforts.




(a) (b)

Figure 3 - Graph of the mean flexural strength and mean modulus of elasticity of the sealing plates.

Furthermore, the superior strength results in the 90° (weft) direction compared to the 45° direction can be attributed to the fact that it is a fabric and not loose fibers. The fabric has fibers braided at right angles between them, so the weft direction, despite being more spaced, still has long longitudinal fibers, different from the 45° direction, which due to the geometry of the specimens only has short fibers. Table 1 presents a summary of the test results, as well as its parameters. The values explained in the result were the means of the specimens, obtained for each direction followed by their standard deviation. As recommended by ASTM D790 [14], from the bending tests it is possible to obtain characteristic parameters of the studied composite, among them, the maximum stress, and the Young's modulus.

Table 1 - Summary of flexural properties of fence plates

| **Fiber direction** | **Direction 0°** | **Direction 45°** | **Direction 90°** |
|---|---|---|---|
| Average flexural strength (MPa) | 37,21 | 16,91 | 21,57 |
| Flexural strength standard deviation | 0,90 | 1,62 | 5,79 |
| Average Young's modulus (GPa) | 10,42 | 2,50 | 3,79 |
| Standard deviation of the Young's modulus | 1,08 | 0,36 | 1,03 |

# 3 Conclusions

In the present work, vegetable composites reinforced with jute fiber fabric were evaluated for their mechanical behavior. These composites were laminated with 40% of jute fiber fabric in a vegetable polyurethane matrix, based on Imperverg castor bean, compressed with the aid of fixatives. For compression molding boards, a study was made of the influence of fiber direction on mechanical properties. Thus, three directions were tested: 0° direction (warp), 45° direction and 90° direction (weft). It was found through a monoatomic bending test, that in the main direction of the fiber, the warp of the fabric, the composite material presents the best strength and the highest stiffness, reaching 37.2±0.9 MPa and 10,4±1.1 GPa, respectively. The other directions presented: 45° direction - 16.9±1.6 MPa and 2,5±0.4 GPa; 90° direction - 21.6±5.8 MPa and 3.8±1.0 GPa. Compared to ANSI A208.1 criteria, composites in the main direction meet the criteria for industrial laminates.

From an environmental and economic point of view, the use of plant fibers in composites is a point of interest for the present and future of research in the country. Therefore, given all the analyzes carried out, the use of vegetable fibers as reinforcement can be seen as an alternative in the field of structural engineering.

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**Authorship statement.** The authors hereby confirm that they are the sole liable persons responsible for authorship of this work, and that all material that has been herein included as part of the present paper is either property (and authorship) of the authors.

# References

[1] L. Klotz, M. Horman, and M. Bodenschatz, "A lean modeling protocol for evaluating green project delivery," Lean Constr. J., vol. 3, no. 1, pp. 1–18, 2007.
[2] E. Iacovidou, P. Purnell, and M. K. Lim, "The use of smart technologies in enabling construction components reuse: A viable method or a problem creating solution?" J. Environ. Manage., vol. 216, pp. 214–223, 2018, doi: 10.1016/j.jenvman.2017.04.093.
[3] J. Gardiner, "Exploring the emerging design territory of construction 3D printing-project led architectural research," RMIT Univ. Melbourne, Aust., 2011.
[4] R. D. S. G. Campilho, Natural fiber composites, 1st Edition. Taylor & Francis, 2015.
[5] K. Joseph, R. D. Tolêdo Filho, B. James, S. Thomas, and L. H. de Carvalho, "a Review on Sisal Fiber Reinforced Polymer Composites," Rev. Bras. Eng. Agrícola e Ambient., vol. 3, no. 3, pp. 367–379, 1999, doi: 10.1590/1807-1929/agriambi.v3n3p367-379.
[6] F. Pacheco-Torgal and S. Jalali, "Cementitious building materials reinforced with vegetable fibres: A review," Constr. Build. Mater., vol. 25, no. 2, pp. 575–581, 2011, doi: 10.1016/j.conbuildmat.2010.07.024.
[7] M. A. Esmeraldo, "Preparação De Novos Compósitos Suportados Em Matriz De Fibra Vegetal / Natural," Universidade Federal Do Ceará, 2006.
[8] Nações Unidas Brasil, "A ONU e os assentamentos humanos," 2020. https://nacoesunidas.org/acao/assentamentos-humanos/ (accessed Aug. 13, 2020).
[9] FENAE, "Minha Casa Minha Vida terá o da história em 2020," 2019. https://www.fenae.org.br/portal/fenae-portal/noticias/minha-casa-minha-vida-tera-o-menor-orcamento-da-historia-em-2020-8A19A3046D127117016D129F73D059F8.htm (accessed Aug. 14, 2020).
[10] P. Wambua, J. Ivens, and I. Verpoest, "Natural fibres: Can they replace glass in fibre reinforced plastics?" Compos. Sci. Technol., vol. 63, no. 9, pp. 1259–1264, 2003, doi: 10.1016/S0266-3538(03)00096-4.
[11] R. M. Jones, "Mechanics Of Composite Materials." Taylor & Francis, p. 519, 1999.
[12] Imperveg, "Imperveg® Agt 1315," Datasheet, 2018. http://imperveg.com.br/wp-content/uploads/2015/05/FICHA-TÉCNICA-IMPERVEG-AGT-1315.pdf (accessed Sep. 11, 2020).
[13] ASTM INTERNATIONAL, "ASTM D790 - Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.," Annual Book of ASTM Standards. pp. 1–12, 2002, doi: 10.1520/D0790-15E02.
[14] ASTM INTERNATIONAL, "ASTM D790 - Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.," Annual Book of ASTM Standards. pp. 1–12, 2002, doi: 10.1520/D0790-15E02.