ADDITION OF MINERAL AND NATURAL FILLERS IN POLYMER COMPOSITES: MECHANICAL BEHAVIOR IN TENSILE

ADIÇÃO DE CARGAS MINERAL E NATURAL EM COMPÓSITOS POLIMÉRICOS: COMPORTAMENTO MECÂNICO EM TRAÇÃO

ADICIÓN DE CARGAS MINERALES Y NATURALES EN COMPUESTOS POLIMÉRICOS: COMPORTAMIENTO MECÁNICO A TRACCIÓN

10.56238/edimpacto2025.041-001

Larissa dos Santos Borges[1], Roberto Yuri Costa Dias[2], Roberto Tetsuo Fujiyama[3]

ABSTRACT

Technological development in engineering is linked to the generation of new materials. Therefore, expanding the range of materials available for various applications is highly relevant. Composites are emerging as a class of materials that enhance this concept. This study performed the mechanical characterization of polymer matrix composites with different particulate fillers. The materials selected for testing as reinforcement were industrial talc, wood residue, and aerosil. To obtain the mechanical properties of the composites, test specimens were fabricated from molds with standardized dimensions according to ASTM D638. To obtain the mass required for the fabrication of four samples, the silicone molds were completely filled, and the load volume was weighed. Due to the variation in material densities, different masses and mass fractions were measured. The matrix used was unsaturated terephthalic polyester resin, and the MEK (Methyl Ethyl Ketone) V388 catalyst was also used to accelerate the curing process. Subsequently, tensile strength tests were carried out, obtaining average maximum stress values of 14.05 (±2.73) MPa, 11.76 (±1.70) MPa and 32.26 (± 4.37) MPa for the composites with talc, wood residue and aerosil fillers, respectively.

Keywords: Particulate Composites. Talc. Jatobá Residue. Aerosil. Mechanical Properties.

RESUMO

O desenvolvimento tecnológico na engenharia está relacionado a geração de novos materiais. Nesse sentido, a ampliação das possibilidades de materiais disponíveis para variadas aplicações possui grande relevância. Os compósitos surgem como uma classe de materiais que valoriza tal ideia. Este estudo realizou a caracterização mecânica de compósitos de matriz polimérica com diferentes cargas particuladas. Os materiais selecionados para serem testados como reforço foram talco industrial, resíduo de madeira e

[1] Master in Mechanical Engineering. Universidade Federal do Pará.
E-mail: larissa.borges@ananindeua.ufpa.br Orcid: https://orcid.org/0000-0002-7809-978X
Lattes: http://lattes.cnpq.br/7459210958889959
[2] Undergraduate in Mechanical Engineering. Universidade Federal do Pará. E-mail: yuricostad@gmail.com
Orcid: https://orcid.org/0009-0008-6386-2667 Lattes: http://lattes.cnpq.br/1066558959052005
[3] Dr. in Metallurgical and Materials Engineering. Universidade Federal do Pará.
E-mail: fujiyama.ufpa@gmail.com Orcid: https://orcid.org/0000-0002-2738-6666
Lattes: http://lattes.cnpq.br/3165747089941318

aerosil. Para a obtenção das propriedades mecânicas dos compósitos foram confeccionados corpos de prova a partir de moldes com dimensões padronizadas conforme a norma ASTM D638, para a obtenção da massa necessária para a fabricação de quatro amostras, os moldes de silicone são complemente preenchidos e o volume de carga é pesado, devido a variação da densidade dos materiais, são aferidas diferentes massas e frações mássicas. A matriz utilizada foi a resina poliéster terefitálica insaturada e também foi utilizado o catalisador MEK (Metil Etil Cetona) V388 para acelerar o processo de cura das amostras. Posteriormente foram realizados ensaios de resistência à tração, sendo obtidos os valores médios de tensão máxima de 14,05 (±2,73) MPa, 11,76 (±1,70) MPa e 32,26 (± 4,37) MPa para os compósitos com cargas de talco, resíduo de madeira e aerosil, respectivamente.

Palavras-chave: Compósitos Particulados. Talco. Resíduo de Jatobá. Aerosil. Propriedades Mecânicas.

RESUMEN

El desarrollo tecnológico en ingeniería está ligado a la generación de nuevos materiales. Por lo tanto, ampliar la gama de materiales disponibles para diversas aplicaciones es sumamente relevante. Los compuestos están emergiendo como una clase de materiales que potencian este concepto. Este estudio realizó la caracterización mecánica de compuestos de matriz polimérica con diferentes rellenos particulados. Los materiales seleccionados para ensayos como refuerzo fueron talco industrial, residuos de madera y aerosil. Para obtener las propiedades mecánicas de los compuestos, se fabricaron probetas a partir de moldes con dimensiones estandarizadas según la norma ASTM D638. Para obtener la masa requerida para la fabricación de cuatro muestras, se llenaron completamente los moldes de silicona y se pesó el volumen de la carga. Debido a la variación en las densidades del material, se midieron diferentes masas y fracciones másicas. La matriz utilizada fue resina de poliéster tereftálico insaturado, y también se empleó el catalizador MEK (metil etil cetona) V388 para acelerar el proceso de curado. Posteriormente se realizaron ensayos de resistencia a tracción, obteniendo valores promedio de tensión máxima de 14,05 (±2,73) MPa, 11,76 (±1,70) MPa y 32,26 (± 4,37) MPa para los compuestos con cargas de talco, residuo de madera y aerosil, respectivamente.

Palabras clave: Compuestos Particulados. Talco. Residuos de Jatobá. Aerosil. Propiedades Mecánicas.

1 INTRODUCTION

Since the dawn of humanity, the use and modification of materials from the different existing classes has been fundamental for the maintenance of life, adding factors that enable social, economic and technological development. However, from the manufacture and exaggerated consumption of products, especially after the consolidation of the Industrial Revolution, it is verified that there is a demand for new materials in order to replace traditional raw materials, especially those from non-renewable sources. The class of composite materials emerges as a possibility of tests for the development of new materials. In this sense, this work aims to evaluate the use of industrial talc, jatoba wood residue and aerosil in polymeric composites.

Among the minerals used by the industry and disseminated in the literature, there is talc, a powder widely used as a thickening agent and for finishing parts. Called hydrated magnesium silicate, talc has a great absorptive capacity due to its extensive surface area (Câmara, 2003). After the mineral is ground, talc has a diversity of applications in various industrial processes, it is possible to mention its use in the textile, ceramics and pharmaceutical industries, with the production of various products, such as insecticides, rubbers, paints, refractories and papers (Loyola, 2010 apud Bezerra, 2003)

Aerosil is made up of glass microspheres, it is an amorphous powder of white color, it has no smell or taste, it has submicroscopic dimensions. It is called colloidal silica, or colloidal silicon dioxide, the small dimensions of the particles and its considerable contact area allow good flow characteristics (Ribeiro, 2015). The alteration of rheological properties of liquid systems stands out as one of the main applications of this material, through the generation of a network of SiO (Silicon Oxide) aggregates, providing fluidity and desired working conditions (Hard, 2013).

One of the most used natural resources globally is wood, and it is possible to make numerous materials with the most varied geometries using this raw material, it is possible to mention sectors such as the furniture industry and civil construction with wide use of this material, hence its great importance for society (Pereira *et al*., 2011). In this sense, the considerable production of waste from the processing of wood is also evaluated, which mostly has no applicability, so it is important to search for ways to promote the reuse of this waste, reducing the environmental impacts resulting from such disposal (Pinto *et al*., 2016; Marie *et al*., 2024).

The wood of the Jatobá (*Hymenaea courbaril*) comes from a tree present in regions from Mexico to southern Brazil, observed in high-lowland forests, upland, clayey soils, and its striking characteristics are trunk height and diameter. In addition to its use for furniture and construction, the use of this wood by indigenous people in the manufacture of canoes is verified (Hopkins, 2004).

The use of natural materials in polymeric composites aims to provide alternatives to traditionally used synthetic materials, such as glass and carbon fibers (Lima et al., 2013; Cardoso et al., 2023; Dias et al., 2024; Soares et al., 2024; Daly et al., 2024). Research with this bias has been carried out, especially aiming at applications at the structural, mechanical and industrial levels (Fujiyama *et al*., 2013; Teixeira *et al*., 2022; Cardoso *et al*., 2023).

Tests using the selected raw materials applied to composites have already been carried out. Watai and Bonse (2014) conducted tests using talc in the matrix composition with polypropylene (PP) tenacified with elastomer-ethylene-propylenemonomer diene (EPDM) with a load of saw dust. Ribeiro (2015) conducted research evaluating the mechanical behavior in traction and flexure of polymeric composites with natural fiber from the inclusion of mederia and aerosil powder. Dos Santos *et al*., 2018 produced composite material boards with polyester matrix with loads of different types of wood waste.

Therefore, the present work aims at the mechanical characterization in traction of polymeric composites with the insertion of industrial talc, jatoba wood residue and aerosil. Specimens with geometry according to ASTM D638 were made to perform tensile strength tests to obtain the mechanical properties of each composite configuration.

2 MATERIALS AND METHODS

2.1 MATERIALS

The materials tested as reinforcement were provided by the Composite Materials Research Group (GPMAC) of the Federal University of Pará (UFPA). The charges were used in the form of particles. The wood residue used was from the tree *Hymenaea courbaril*, known as Jatobá, widely used in the manufacture of furniture. The residue and the industrial talc were subjected to sieving to standardize their grains, granulometry sieves with meshes 14 and 35, equivalent to openings of 1.4 mm and 500 µm, were used for the wood residue and talc shards, respectively. The aerosil was used in its raw form.

The specimens were manufactured using silicone molds. To obtain the amount of load necessary for the preparation of the samples, the molds, which have cavities for the production of four test specimens, are completely filled for subsequent weighing of the materials. Figure 2 presents a flowchart representative of the processing to quantify the load mass necessary for the production of the specimens of each composite by means of the mold filling, the raw materials used in (a) industrial talc, (b) Jatobá waste, and (c) aerosil. Table 1 shows the quantified masses and mass fractions of the composites.

Figure 1

Representative processing flowsheet for quantification of the load mass required for the production of the specimens

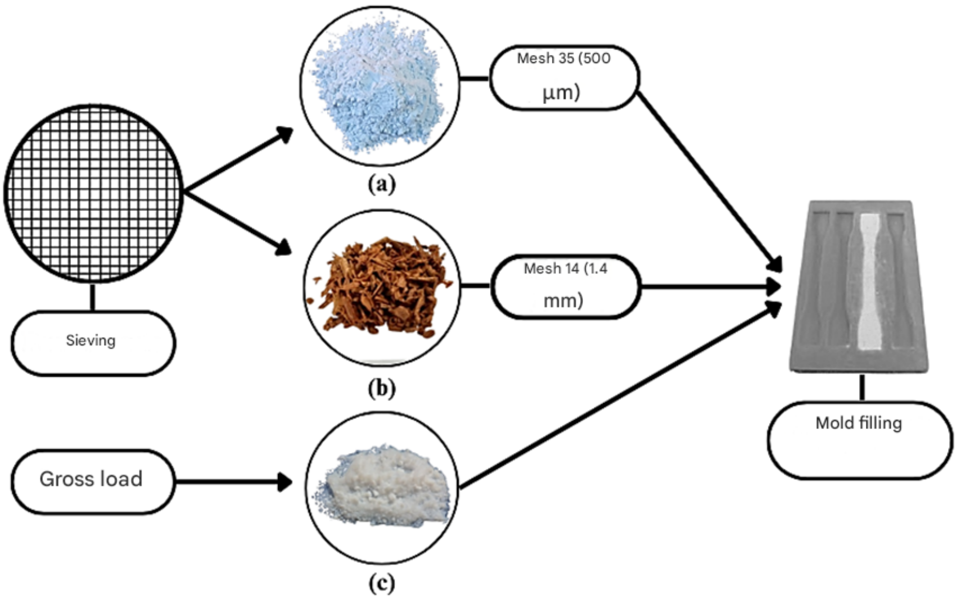


Table 1

Mass of the loads and mass fractions of the composites

Material	Mass (g)	Mass fraction (%)
Aerosil	1,33	2,16
Wood residue	7,90	12,84
Industrial talc	18,44	22,98

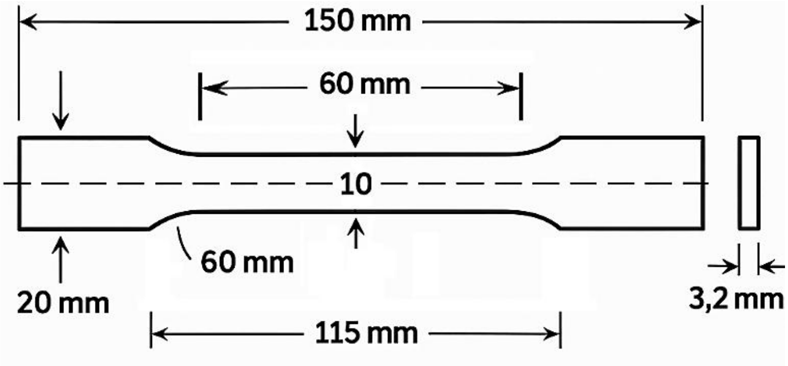
Due to the variation in the density of the loads, for the same filled volume of the mold, different masses and fractions are obtained, considering that the reference of the mass necessary for the manufacture of four samples is based on the total filling of the mold. The matrix used was the unsaturated and pre-accelerated polyester terephthalic resin, together with the catalyst MEK (Methyl Ethyl Ketone) V388 due to the curing process of the specimens requiring a lot of time. The proportion used was 0.5%, by mass, of catalyst. The required matrix mass is obtained using the same technique used for particulate charges.

2.2 METHODS

To carry out the mechanical characterization, the geometry of the mold cavities was standardized according to ASTM D638. Figure 2 shows the dimensions of the specimens according to the standard.

Figure 2

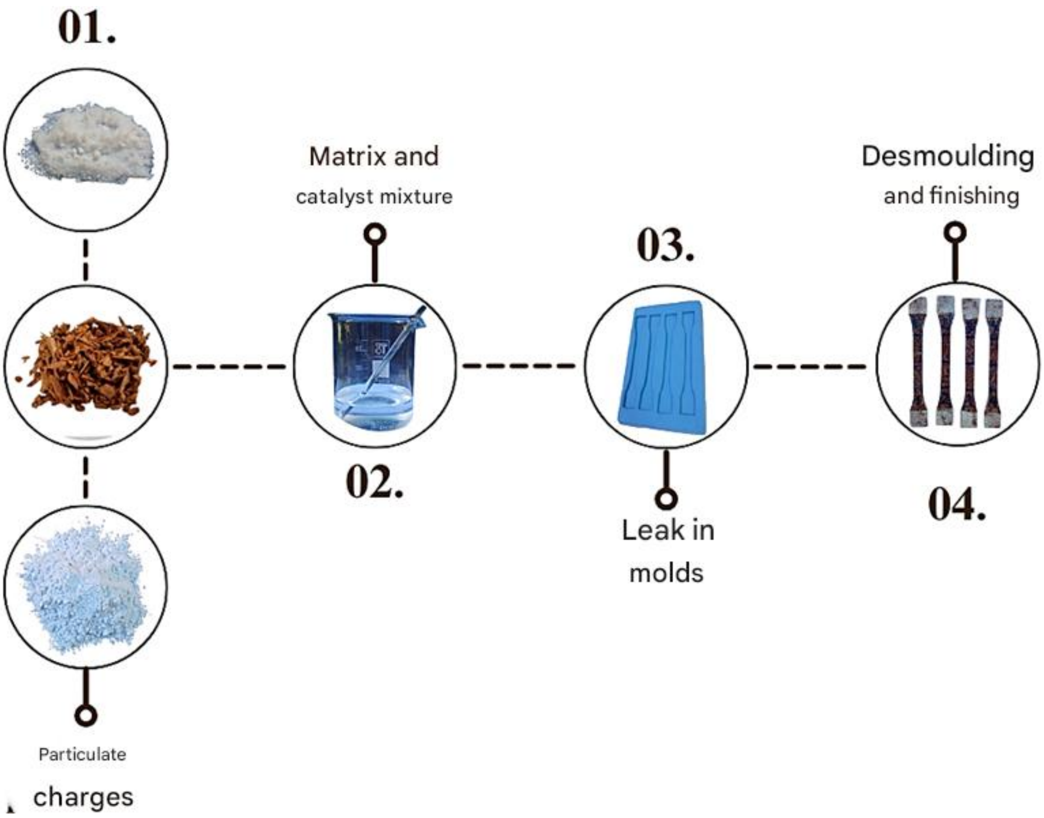
Specimen dimensions according to ASTM D638



The flowchart shown in Fig. 3 illustrates the steps in the process of manufacturing the specimens. Step 01 represents the obtaining of the particulate charges, step 02 concerns the mixture of the charges with the matrix and the catalyst, step 03 mentions the leakage of the mixtures in the cavities of the silicone molds and step 04 represents the demolding of the test specimens to perform finishing, markings and numbering.

Figure 3

Illustrative flow chart of the specimen manufacturing process



The 4 specimens were manufactured for each configuration, totaling 12 samples. The mechanical properties were obtained from uniaxial tensile strength tests. The tests were carried out in an EMIC DL 10000 universal testing machine, with a load cell of 5 kN and a displacement speed of 5 mm/min, according to the guidelines of the technical standard ASTM D638. Images were also recorded using the Vedo 1000x USB LED digital microscope. Figures 4 (a) and 4 (b) show, respectively, the testing machine used and the microscope.

Figure 4

a) Universal EMIC testing machine b) Digital microscope

(a)

(b)

3 RESULTS AND DISCUSSIONS

The manufacturing process proved to be efficient for the production of specimens with different types of particulate loads. The selection of polyester resin as the matrix phase was beneficial, adding cost, availability and work time factors, making it possible to completely fill the mold in a timely manner. The geometry of the specimens also attests to the reproducibility of the method employed.

After performing the tensile strength tests, the following properties were assessed: Maximum stress (MPa), Maximum strain (mm/mm) and Modulus of elasticity (MPa) for each configuration of the manufactured composite and for the pure matrix. Table 2 presents the mean values of each property measured.

Table 2

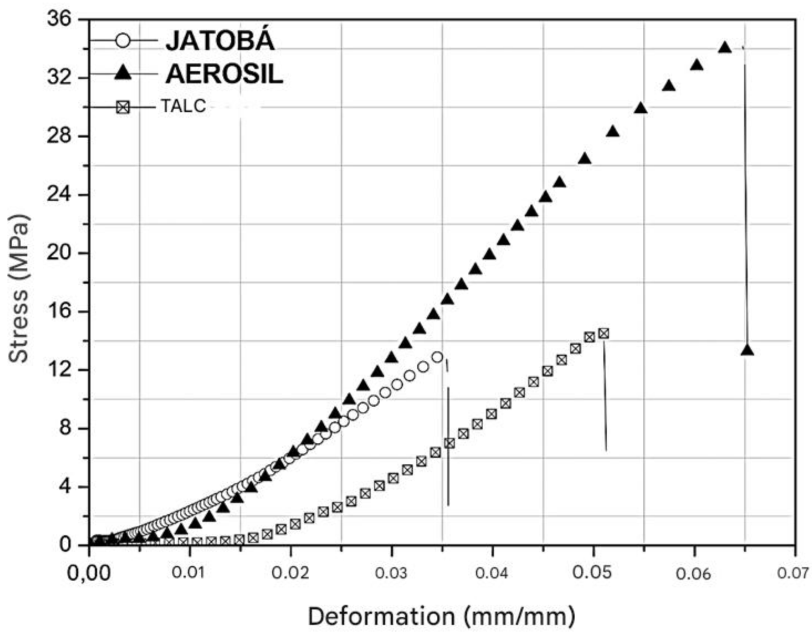
Mechanical properties of composites

Material	Max. Voltage (MPa)	Deformation (mm/mm)	Modulus of Elasticity (MPa)
Talc+Polyester	14.05 ± 2.73	0.042 ± 0.006	977.78 ± 17.54
Jatoba + Polyester	11.76 ± 1.70	0.034 ± 0.005	480.70 ± 38.90
Aerosil + Polyester	32.26 ± 4.37	0.094 ± 0.023	988.22 ± 120.03
Polyester Matrix	26.94 ± 4.60	0.016 ± 0.003	1893.10 ± 151.82

Figure 5 presents the graph Stress x Strain of the fabricated composites, in which representative curves of the materials are presented from the average of the specimens for each composite configuration. From the curves it is possible to validate the results presented in Table 2.

Figure 5

Graph of the behavior Stress x strain of composites

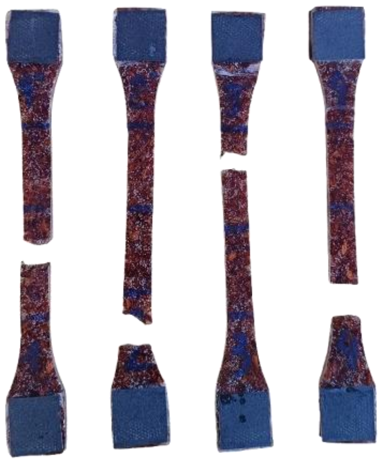


It is evaluated that only the aerosil acted as an effective reinforcement of the polymeric matrix, raising its tensil strength from 26.94 (MPa) to 32.26 (MPa), the Jatobá residue and the industrial Talc acted only as cargo. In addition, the aerosil-reinforced composite also showed higher maximum deformation compared to the others and lower stiffness only than pure polyester. However, the variation in the density of the fillers and, consequently, in the mass used in each configuration produced, makes it difficult to carry out a concrete evaluation about which composite presented a more efficient mechanical performance. After the tests, it was found that the failure of the materials occurred in the region of the useful length of the specimens. Figures 6 (a), 6 (b) and 6 (c) show the appearance of the specimens after the fracture recorded using the microscope.

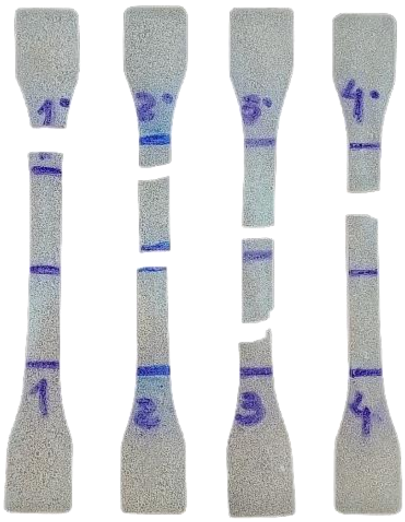
Figure 6

Appearance of specimens with loads of (a) talc, (b) jatoba residue and (c) aerosil after fracture

(a)



(b)



(c)

From the analysis of the fracture surface of the materials, the presence of defects called porosities or voids was verified, resulting from air bubbles that end up retained in the samples during the curing process of the materials. Its presence results in losses in the mechanical performance of the manufactured composites, as they act as stress concentrator points, favoring the appearance and propagation of cracks, resulting in early failure of the specimen.

4 CONCLUSION

The present work aimed to mechanically characterize polymeric composites with the insertion of industrial talc, jatoba wood residue and aerosil. It was verified that only the aerosil acted as effective reinforcement when inserted into the matrix, having surpassed the tensile strength of pure polyester. In addition, the presence of porosity defects in the specimens in all composite configurations was verified, such a circumstance results in mechanical damage, reducing the maximum strength to be obtained. From the results, the use of these composites in applications that require low mechanical stresses is envisioned. The use of tests for the development of new materials is evaluated as important, especially with regard to the reuse of waste, aiming to generate added value to the substrates.

ACKNOWLEDGMENT

The authors thank PROPESP/UFPA for the Institutional Scientific Initiation Scholarship Program (PIBIC) and the scholarships granted to undergraduate students. They also thank CAPES, CNPq, and the Laboratory of Composite Materials of the Federal University of Pará for the experiments carried out in this work. The authors gratefully acknowledge the support of FEM/ITEC/UFPA and PPGEM/ITEC/UFPA.

REFERENCES

Bezerra, O. M. D. P. A., Dias, E. C., Galvão, M. A. M., & Carneiro, A. P. S. (2003). Talcose entre artesãos em pedra-sabão em uma localidade rural do Município de Ouro Preto, Minas Gerais, Brasil. Cadernos de Saúde Pública, 19(6), 1751–1759. https://doi.org/10.1590/S0102-311X2003000600021

Camara, A. L. (2008). Uso de talco nacional como aditivo adsorvente de piches e materiais pegajosos no processo de fabricação do papel [Master’s dissertation, Universidade Federal de Minas Gerais]. Repositório Institucional da UFMG. http://hdl.handle.net/1843/BUOS-8DQF4P

Cardoso, R. L. B., da Silva Rodrigues, J., Ramos, R. P. B., de Castro Correa, A., Leão Filha, E. M., Monteiro, S. N., da Silva, A. C. R., Fujiyama, R. T., & Candido, V. S. (2023). Use of yarn and carded jute as epoxy matrix reinforcement for the production of composite materials for application in the wind sector: A preliminary analysis for the manufacture of blades for low-intensity winds. Polymers, 15(18), 3682. https://doi.org/10.3390/polym15183682

Cardoso, R. L. B., Ramos, R. P. B., Leão Filha, E. M., Ribeiro, M. M., Candido, V. S., Rodrigues, J. da S., Silva, D. S., Junio, R. F. P., Monteiro, S. N., & Fujiyama, R. T. (2024). Modelling and analysis of jute fiber reinforced epoxy composite in the development of wind blade for low intensity winds. Journal of Materials Research and Technology, 28, 3619–3630. https://doi.org/10.1016/j.jmrt.2023.12.151

Daly, M., Chihi, M., Bouraoui, C., & Tarfaoui, M. (2024). Avanço em materiais compósitos: Explorando propriedades termomecânicas de compósitos de aerosil/policarbonato por meio de manufatura aditiva. Revista de Processos de Fabricação, 131, 1770–1783. https://doi.org/10.1016/j.jmapro.2024.10.003

Dias, R. Y. C., Soares, R. V., Maia, P. V. M., Santos, J. E. M., Miranda, I. R. S., Paschoal, W., & Fujiyama, R. T. (2024). Preliminary indication approach of jute fiber fabric with polyester for bumpers of passenger cars. SAE Technical Papers, 2024, 1–14. https://doi.org/10.4271/2024-36-0149

Dos Santos, R. R., Ribeiro, M. M., Fujiyama, R. T., & Branco, C. T. N. M. (2018). Placas laminadas de compósito poliéster, tecido de juta e resíduos de madeira. Estudos Tecnológicos em Engenharia, 12(2), 68–77. https://doi.org/10.4013/ete.2018.122.04

Fujiyama, R., Darwish, F., & Pereira, M. (2013). Mechanical characterization of sisal fiber reinforced cement mortar. In Proceedings of the 13th International Conference on Fracture (ICF 2013) (Vol. 1, pp. 401–407). https://doi.org/10.1063/2.1406102

Hard Comércio de Fixadores e Resinas Ltda. (2013). Boletim técnico: Aerosil 200. http://www.hard.com.br/xpcontent/uploads/2013/02/1043_BOLETIM_TCNICO__AEROSIL_200.pdf

Hopkins, M. J. G. (2004). Espécies arbóreas da Amazônia: 8. Jatobá, Hymenaea courbaril. Embrapa Amazônia Oriental. https://repositorio.inpa.gov.br/handle/1/36153

Lima, L. S., Branco, C. T. N. M., Santos, R. M. C., Lima, F. V. M., da Costa, D. S., El Banna, W. R., & Fujiyama, R. T. (2013). Laminated composite of sisal and curaua fibers to different settings for use in bumper cars. SAE Technical Paper Series, 2013(36-0603). https://doi.org/10.4271/2013-36-0603

Loyola, R. C. B. R., Carneiro, A. P. S., Silveira, A. M., La Rocca, P. D. F., Nascimento, M. S., & Chaves, R. H. D. A. (2010). Efeitos respiratórios da exposição ao talco industrial em ex-trabalhadores de mineração. Revista de Saúde Pública, 44(3), 541–547. https://doi.org/10.1590/S0034-89102010005000017

Mendonça, A. G. S., Dias, R. Y. C., Soares, R. V., Borges, L. S., Maia, P. V. M., & Fujiyama, R. T. (2024). Polyester composite and waste of natural materials recyclable fracture aspect after tensile test. Revista de Gestão Social e Ambiental, 18, 1–14. https://doi.org/10.24857/rgsa.v18n5-180

Pereira, L. C. de O., Takahashi, R., Vilhena, R. V., Oliveira, D. R. de, & Fujiyama, R. T. (2011). Caracterização de resíduos de madeira e fibras de sisal para fabricação de materiais compósitos de matriz poliéster. In *XXXIX Congresso Brasileiro de Educação emelő

Bezerra, O. M. D. P. A., Dias, E. C., Galvão, M. A. M., & Carneiro, A. P. S. (2003). Talcose entre artesãos em pedra-sabão em uma localidade rural do Município de Ouro Preto, Minas Gerais, Brasil. Cadernos de Saúde Pública, 19(6), 1751–1759. https://doi.org/10.1590/S0102-311X2003000600021

Camara, A. L. (2008). Uso de talco nacional como aditivo adsorvente de piches e materiais pegajosos no processo de fabricação do papel [Master's dissertation, Universidade Federal de Minas Gerais]. Repositório Institucional da UFMG. http://hdl.handle.net/1843/BUOS-8DQF4P

Cardoso, R. L. B., da Silva Rodrigues, J., Ramos, R. P. B., de Castro Correa, A., Leão Filha, E. M., Monteiro, S. N., da Silva, A. C. R., Fujiyama, R. T., & Candido, V. S. (2023). Use of yarn and carded jute as epoxy matrix reinforcement for the production of composite materials for application in the wind sector: A preliminary analysis for the manufacture of blades for low-intensity winds. Polymers, 15(18), 3682. https://doi.org/10.3390/polym15183682

Cardoso, R. L. B., Ramos, R. P. B., Leão Filha, E. M., Ribeiro, M. M., Candido, V. S., Rodrigues, J. da S., Silva, D. S., Junio, R. F. P., Monteiro, S. N., & Fujiyama, R. T. (2024). Modelling and analysis of jute fiber reinforced epoxy composite in the development of wind blade for low intensity winds. Journal of Materials Research and Technology, 28, 3619–3630. https://doi.org/10.1016/j.jmrt.2023.12.151

Daly, M., Chihi, M., Bouraoui, C., & Tarfaoui, M. (2024). Avanço em materiais compósitos: Explorando propriedades termomecânicas de compósitos de aerosil/policarbonato por meio de manufatura aditiva. Revista de Processos de Fabricação, 131, 1770–1783. https://doi.org/10.1016/j.jmapro.2024.10.003

Dias, R. Y. C., Soares, R. V., Maia, P. V. M., Santos, J. E. M., Miranda, I. R. S., Paschoal, W., & Fujiyama, R. T. (2024). Preliminary indication approach of jute fiber fabric with polyester for bumpers of passenger cars. SAE Technical Papers, 2024, 1–14. https://doi.org/10.4271/2024-36-0149

Dos Santos, R. R., Ribeiro, M. M., Fujiyama, R. T., & Branco, C. T. N. M. (2018). Placas laminadas de compósito poliéster, tecido de juta e resíduos de madeira. Estudos Tecnológicos em Engenharia, 12(2), 68–77. https://doi.org/10.4013/ete.2018.122.04

Fujiyama, R., Darwish, F., & Pereira, M. (2013). Mechanical characterization of sisal fiber reinforced cement mortar. In Proceedings of the 13th International Conference on Fracture (ICF 2013) (Vol. 1, pp. 401–407). https://doi.org/10.1063/2.1406102

Hard Comércio de Fixadores e Resinas Ltda. (2013). Boletim técnico: Aerosil 200. http://www.hard.com.br/xpcontent/uploads/2013/02/1043_BOLETIM_TCNICO__AEROSIL_200.pdf

Hopkins, M. J. G. (2004). Espécies arbóreas da Amazônia: 8. Jatobá, Hymenaea courbaril. Embrapa Amazônia Oriental. https://repositorio.inpa.gov.br/handle/1/36153

Lima, L. S., Branco, C. T. N. M., Santos, R. M. C., Lima, F. V. M., da Costa, D. S., El Banna, W. R., & Fujiyama, R. T. (2013). Laminated composite of sisal and curaua fibers to different settings for use in bumper cars. SAE Technical Paper Series, 2013(36-0603). https://doi.org/10.4271/2013-36-0603

Loyola, R. C. B. R., Carneiro, A. P. S., Silveira, A. M., La Rocca, P. D. F., Nascimento, M. S., & Chaves, R. H. D. A. (2010). Efeitos respiratórios da exposição ao talco industrial em ex-trabalhadores de mineração. Revista de Saúde Pública, 44(3), 541–547. https://doi.org/10.1590/S0034-89102010005000017

Mendonça, A. G. S., Dias, R. Y. C., Soares, R. V., Borges, L. S., Maia, P. V. M., & Fujiyama, R. T. (2024). Polyester composite and waste of natural materials recyclable fracture aspect after tensile test. Revista de Gestão Social e Ambiental, 18, 1–14. https://doi.org/10.24857/rgsa.v18n5-180

Pereira, L. C. de O., Takahashi, R., Vilhena, R. V., Oliveira, D. R. de, & Fujiyama, R. T. (2011). Caracterização de resíduos de madeira e fibras de sisal para fabricação de materiais compósitos de matriz poliéster. In XXXIX Congresso Brasileiro de Educação em Engenharia (Vol. 1). Blumenau. https://doi.org/10.37423/210904731

Pinto, L. S. D., Matos, C. C., & Da Silva, M. L. F. (2016). Resíduos sólidos de madeira: Aplicabilidade de resíduo de serragem de MDF no design de ambientes. Blucher Design Proceedings, 2(9), 4253–4262. https://doi.org/10.5151/despro-ped2016-0365

Ribeiro, M. M. (2015). Comportamento mecânico em tração/flexão e aspecto fractográfico de matriz poliéster com pó de Aerosil e de madeira com a inclusão de fibras curtas de sisal e juta [Master's dissertation, Universidade Federal do Pará]. CAPES. https://sucupira-legado.capes.gov.br/sucupira/public/consultas/coleta/trabalhoConclusao/viewTrabalhoConclusao.jsf?popup=true&id_trabalho=3507771

Soares, R., Dias, R., de Mendonça Maia, P., Junior, W., & Fujiyama, R. T. (2024). Presentation of biocomposites for proposal for use in car bumpers. SAE Technical Paper Series, 2024(36-0148). https://doi.org/10.4271/2024-36-0148

Teixeira, F. P., Lima, V. N., Moutinho, D. J. C., & Fujiyama, R. T. (2022). Mechanical properties and fractography of cement-based composites reinforced by natural piassava and jute fibers. Cerâmica, 68, 60–66. https://doi.org/10.1590/0366-69132022683853174