Ballistic Energy Absorption of Thermally Aged DGEBA/TETA System and Fique-Fabric Reinforced Epoxy Composite

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Abstract: For many applications, such as vests or parts of vests, the fibers are used in fabric, mat, or mesh. Ballistic resistance properties are also improved by the development of special fabrics architectures. It is known that heat and oxygen are the main factors in the aging process of polymers. The mechanisms of aging by oxidation can be investigated by monitoring the mechanical properties of a material exposed to prolonged aging in an oven, which is called the accelerated aging process by thermal oxidation. In previous studies, the epoxy matrix composite reinforced with 40% by volume of fique fabric, already tested and with good ballistic performance, was developed and proposed for individual ballistic protection applications. However, the impact of different environmental conditions on the dynamic properties of the composite has not been studied. Therefore, the present study, for the first time, aimed to apply accelerated weathering through high temperature to the composite, as well as to the epoxy matrix, aiming to evaluate the influence of aging.

Keywords: Ballistic tests, Fique fabric, Natural fiber, Composite materials, Epoxy matrix, Aging materials, Thermal aging.

INTRODUCTION

Promoting the green composite concept, many hybrid composites, with synthetic and natural fibers, have been tested [1-4]. Aiming to increase cost benefits, several research studies have reported that polymer composites reinforced with different types of natural fibers, at different ballistic levels, can compete with Kevlar® in terms of ballistic performance. For level I (22 mm) [5]; level III-A (7.62 mm) [6]; and level III (7.62 mm) [7-16]. For many applications, such as vests or [17] parts of vests, the fibers are used in fabric, mat, or mesh format [18]. Ballistic resistance properties have also been improved by the development of special fabric architectures.

In view of the above, it is possible to observe that current ballistic vests are effective, but not optimized in terms of durability. Therefore, consumers want a more eco-friendly, lightweight, and cheap vest. And yet, the purpose of ballistic armor is not just to stop high-velocity projectiles, but to protect the individual from ballistic fragments [8].

Furthermore, thermosetting matrices are generally used to convert the fabric into a rigid plate to obtain good thermal and mechanical property [19]. It is important to mention one of the aspects that represents a barrier to the effective use of natural fibers to replace synthetic ones, as reinforcement in polymer composites, which is the high dispersion of the values found in their mechanical properties. This factor does not allow for an adequate projection of its mechanical performance. The high dispersion of values is explained, from a microscopic point of view, from the fracture of the fiber [20]. Thus, fractures propagate at concentrated points of tension along the fiber, in the longitudinal and transverse directions, and end with its failure.

The fracture process begins close to the defective regions, these are differences in diameter, torsion band, branching, and void failure [20]. With increasing stress forces, fracture occurs within the fiber in terms of detachment between the cellulose microfibrils and their amorphous matrix (hemicellulose + lignin), which is accompanied by small local deformations. Large and permanent deformations are attributed to slippage of microfibrils over each other, significant breakage of cellulose fibrils leads to fiber failure.

The general reasons for this high variability in the properties may be related to growing conditions, the specific region where the plantations are located, and other factors relating to the nature of the fibers and their extraction process. Thus, variability in the physical properties of natural fibers is a natural characteristic

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Figure 1: Common synthetic fibers and epoxy composite ballistic panel reinforced with natural fibers.

associated with irregular morphology both longitudinally and transversely and is reflected in the maximum strength, modulus of elasticity, percentage of elongation, in addition to other characteristics such as diameter [21].

Therefore, the present study, for the first time, presents the influence of thermal aging on the composite reinforced with natural fiber and the epoxy matrix after level I ballistics tests. A statistical study was carried out on the influence of aging.

MATERIALS AND METHODS

Fique-fiber woven fabric was considered as composite's reinforcement. These fique-fiber woven fabrics were cut into dimensions of 15 × 12 cm and placed in an oven at 70 °C for 24 h to remove moisture absorbed by the fiber. Epoxy polymer composed of diglycidyl ether of bisphenol A (DGEBA) and the hardener triethylenetetramine (TETA) was used as matrix. Both DGEBA and TETA were supplied by Epoxyfiber, Rio de Janeiro, Brazil. The mixture of these two components was made with a stoichiometric ratio phr 13, recommended by manufacturer.

Composite plates, with 10 mm of thickness and 40 vol% fique fabric, were produced by the compression process in a metallic mold, applying a pressure of 5 MPa for 24 hours. Layers of fique fabric were carefully hand lay-up inside the mold cavity alternately with a still fluid resin-hardener mix in a predefined proportion of fiber and resin. For determination of each component amount, the epoxy resin density was considered equal to 1.11 g/cm³, and fabric density values were evaluated through tests, obtaining an average of 0.67 g/cm³ for the fique fiber [22].

The fique fabric reinforced epoxy composite and epoxy plates were subjected to accelerated aging test performed in air chambers (Nova Instruments, Brazil) at 170 °C for progressively increasing time lengths (0, 72, 120 and 240 hours). The aging temperature of 170 °C was selected as the limit temperature before degradation in both the epoxy and the fique-fiber woven fabric.

Both composites and epoxy plates, with and without thermal aging, were subjected to ballistics tests using a Gunpower SSS pressure air rifle 4000 psi (Ashford, UK). The ammunition was a commercial 22 mm, weighting 3.3 g. For the impact and residual velocity measurements, a model MK3 Air Chrony gun chronograph (Nové Město,Czech Republic), with a precision of 0.15 m/s, and a model Pal ProChrono gun chronograph(Competition Eletronics, Rockford, IL, USA) , with a precision of 0.31 m/s, were placed, respectively, 10 cm before and after the target. The targets were positioned 5 m away from the rifle, and the bullet trajectory was perpendicular to the target plate. The composites plates were produced with the dimensions of 15 × 12 × 1 cm³, comprising five test-shootings for each plate.

The projectile impact (V_i) and residual (V_R) velocities were measured by chronographs. To compare the tested materials, the energy absorbed by the target (E_{abs}) was estimated applying the difference of kinetic energy before and after impact, as showed by following equation, where "m" is the weight of the projectile [23].

$$E_{abs} = \frac{m(V_i^2 - V_R^2)}{2}$$

The ballistic energy absorption values of five shots in the four types of target samples were statistically treated using the variance analysis (ANOVA) and the Weibull method in terms of the cumulative distribution function [24, 25]. Analysis of variance (ANOVA) was applied in all results to verify, with a 95% confidence level, any significant differences between the averages. In positive cases, the mean values of the results were then compared using the Tukey's test, also called honestly significant difference (HSD). The "q" is a tabulated constant, "EMS" is the error mean square and "r" is the repetitions number for each condition.

$$HSD = q\sqrt{\frac{EMS}{r}}$$

The Weibull distribution is an unusually versatile probability density function for ballistic analysis as it can fit a variety of shapes. The two-parameter Weibull distribution has the following parameters: shape (β) and scale (θ). A logarithm-based linear expression allows the graphical interpretation of the Weibull parameters.

$$\ln\left[\ln\left(\frac{1}{1-F(x)}\right)\right] = \beta.\ln(x) - [\beta.\ln(\theta)]$$

Where x is the ballistic limit, β is the Weibull modulus or shape and θ is the characteristic ballistic limit or scale. The probability plot is a graphical technique for assessing whether a data set follows a given distribution such as the normal or Weibull.

RESULTS AND DISCUSSIONS

The results of ballistic impacts at level I indicated the ballistic energy absorption capacity as a function of the projectile and target response, aging effect, and composite failure mechanisms. Since temperature is an important factor leading to changes in the properties of composites, and that there is an inverse relationship between increasing temperature and the amount of energy absorption due to decreasing hardness and stiffness [2], it is worth noting the behavior of the fique-fabric/epoxy composite at ballistic level I.

Figure **2** to Figure **7** show the ballistic impacts made with 22 caliber on composites with and without thermal aging. It is noted that even after thermal aging the composite did not fragment, however an increase in delamination was also observed as a fracture mechanism after drilling.

The values of the β, θ and R^2 parameters for the E_{abs} in the ballistic test are presented in the Figure **6**

Figure 2: Composite plate without thermal aging (FC-T0) after 22 caliber ballistic test. Details: Absorbed energy in Joules and location of the 5 perforations, perforation, rear of the plate, and front of the plate on the right.

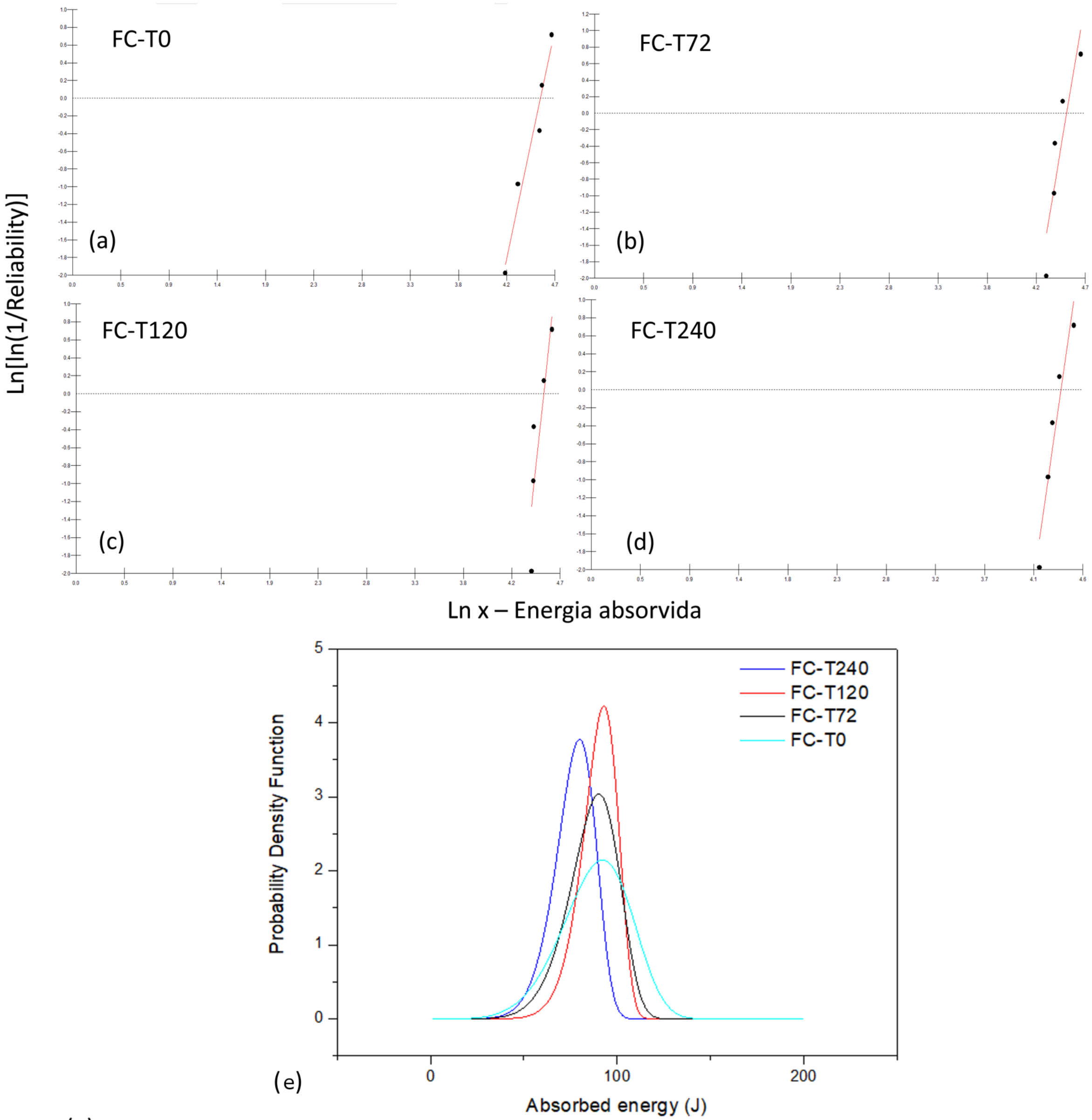
Figure 3: Composite plate with thermal aging for 72 h (FC-T72) after 22 caliber ballistic test.

Figure 4: Composite plate with thermal aging for 120 h (FC-T120) after 22 caliber ballistic test.

Figure 5: Composite plate with thermal aging for 240 h (FC-T240) after 22 caliber ballistic test.

shows the Weibull distribution, as well as the probability density function for the composites.

The composite aged for 72 hours (FC-T72) showed a slight loss of energy absorption when compared to the control group (FC-T0), around 2%. After 120 hours (FC-T120), the composite absorbed 2% more energy compared to FC-T0. The group exposed for 240 hours (FC-T240) showed a decrease in energy absorption of around 13%. The absorbed energy values were not considered significantly different, as shown in Table **1**.



(f)

	β	θ	R^2	Average absorbed energy (J)	Standard deviation
FC-T0	5.474	95.55	0.9583	88.19	18.59
FC-T72	7.524	91.92	0.8193	86.30	13.56
FC-T120	10.73	93.70	0.7689	89.40	10.06
FC-T240	8.261	81.05	0.9219	76.45	11.01

Figure 6: **a**) to **d**) Plots of the Weibull distribution for energy absorbed after level I ballistic impact in composites; **e**) probability density function for unaged and thermally aged composites and **f**) Weibull parameters description.

Table **1** shows the p-value was equal to 0.296, which means that if the hypothesis that the means are equal were rejected, the error would be very high (29.59%). The F test statistic was equal to 1.31 and is in the range of 95% of the accepted critical value. The Tukey test ratified the ANOVA result since there is no significant difference between the means of any pair.

Table **2** presents the values obtained for the epoxy without and with thermal aging. Maximum energy absorption was observed for the epoxy exposed to high temperature for 240 hours (PE-T240) which absorbed 88% of the projectile impact, followed by the group exposed for 72 hours (PE-T72) which absorbed 84%. The third group that obtained the highest energy

Table 1: ANOVA and Tukey Test for the Composite without and with Thermal Aging After Ballistic Impact with caliber 22.

Causes of variation	Degree of freedom (df)	Sum of squares	Mean square	Fcalc	Ftab
Treatments	3	520	173	1.31	3.24
Error	16	2115	132		
Total	19	2635			

Means are not significantly different at 95% confidence level

df	Studentized range distribution (q)	Residual mean square	r	Honestly significant difference (HrSD)
16	4.56	132	5	23
	A	B	C	D
A	0	1.87	1.23	11.7
B	1.87	0	3.10	9.84
C	1.23	3.10	0	12.9
D	11.7	9.84	129	0

Table 2: Energy Absorbed After Level I Ballistic Impact in High Temperature Aged Epoxy

	V_I (m/s)	V_R (m/s)	E_{abs} (J)	$\%E_{abs}$
PE-T0	273.10	121.01	98.54	80.37
PE-T72	276.76	110.64	104.54	84.02
PE-T120	272.80	122.23	97.24	79.92
PE-T240	273.10	93.57	106.67	88.26

absorption was the control group (PE-T0) with 80%, followed by the epoxy aged at high temperature for 120 hours (PE-T120) with absorption of ≈80%.

Figure **7** shows the performance in terms of energy absorption of the epoxy and the composite, with and without thermal aging, after a ballistic test with a 22 caliber. The single-phase exponential decay function has an acceptable fit with respect to the data obtained for the composite. To describe the behavior obtained for the epoxy, a cubic polynomial function was chosen, as it was not possible to observe a possible behavior for longer exposure times.

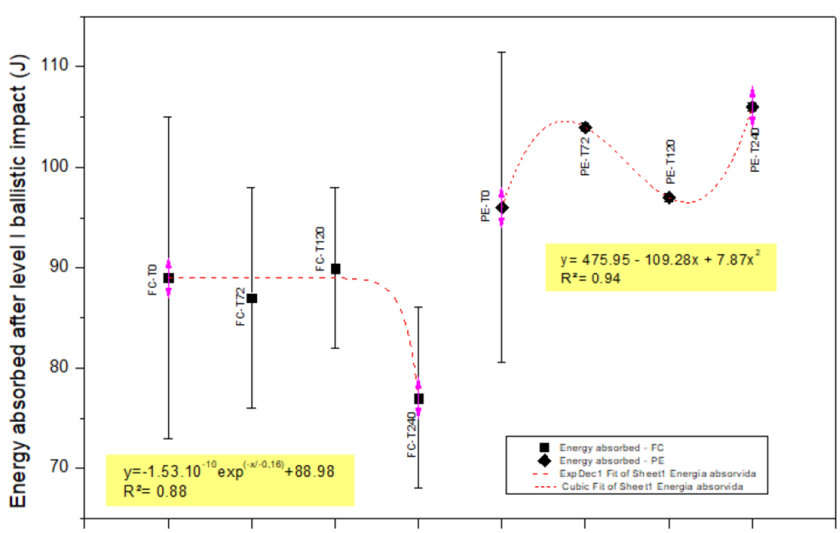


Figure 7: Effect of thermal aging on composite and epoxy after ballistic impact level I.

Ali *et al*. [2] reported that Kevlar 29/ramie fiber reinforced polyester hybrid laminate had its resistance to ballistic impact reduced due to exposure to 103 ºC for 15 minutes. Therefore, temperature is an important factor that leads to changes in the properties of composites as well as the matrix. There is an inverse relationship between increasing temperature and the amount of energy absorption due to decreasing stiffness.

SUMMARY AND CONCLUSIONS

In the present study, for the first time, a level I ballistic study was carried out for thermally aged composite and epoxy plates. Epoxy matrix composites reinforced with 40% by volume of Fique fabric were produced and tested by ballistics tests level I.

- The composite and epoxy plates were subjected to three different times aging in high temperature conditions, were 72, 120, 240 hours.
- After level I ballistic impact, there was a loss of 2% and 13% in energy absorption after 72 hours and 240 hours, indicating a weakening of the strength of the composite structure. In addition, absorbed 1.4% more, compared to FC-T0, after 120 hours (FC-T120). This increase in absorption can be attributed to the absorption of energy through microcracks caused by thermal aging.
- For epoxy plates, the epoxy exposed by 240 hours (PE-T240) absorbed 88% of the projectile impact. The group exposed for 72 hours (PE-T72) absorbed 84%, and the third group exposed by 120 hours (PE-T120) absorbed ≈80%, the latter being equal to that obtained for the control group (PE-T0).
- In summary, a small, but insignificant, increase in level I ballistic energy absorption was observed.

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REFERENCES

[1] S. Y. Nayak, M. T. H. Sultan, S. B. Shenoy, C. R. Kini, R. Samant, A. U. M. Shah e P. Amuthakkannan, "Potential of Natural Fibers in Composites for Ballistic Applications - A Review," Journal of Natural Fibers, vol. 19, nº 5, pp. 1648-1658, 2022. https://doi.org/10.1080/15440478.2020.1787919

[2] A. Ali, Z. R. Shaker, A. Khalina e S. M. Sapuan, "Development of Anti-Ballistic Board from Ramie Fiber," Polymer-Plastics Technology and Engineering, vol. 50, nº 6, pp. 622-634, 2011. https://doi.org/10.1080/03602559.2010.551381

[3] J. Naveen, M. Jawaid, E. S. Zainudin, M. T. H. Sultan e R. Yahaya, "Evaluation of ballistic performance of hybrid Kevlar®/Cocos nucifera sheath reinforced epoxy composites," The Journal of The Textile Institute, vol. 110, nº 8, p. 1179-1189, 2019. https://doi.org/10.1080/00405000.2018.1548801

[4] A. M. R. Azmi, M. T. H. Sultan, A. Hamdan, A. F. M. Nor e K. Jayakrishna, "Flexural and Impact Properties of A New Bulletproof Vest Insert Plate Design Using Kenaf Fibre Embedded With X-Ray Films," Materials Today: Proceedings, vol. 5, nº 5, pp. 11193-11197, 2018. https://doi.org/10.1016/j.matpr.2018.01.143

[5] L. de Mendonça Neuba, R. Pereira Junio, M. Ribeiro, A. Souza, E. de Sousa Lima, F. Garcia Filho, A.-H. Figueiredo, F. Braga, A. Azevedo e S. Monteiro, "Promising Mechanical, Thermal, and Ballistic Properties of Novel Epoxy Composites Reinforced with Cyperus malaccensis Sedge Fiber," Polymers, vol. 12, p. 1776, 2020. https://doi.org/10.3390/polym12081776

[6] N. L. G. J. M. S. L. F. P. W. G. F. F. Costa UO, "Effect of Graphene Oxide Coating on Natural Fiber Composite for Multilayered Ballistic Armor," Polymers, vol. 11, nº 8, p. 1356, 2019. https://doi.org/10.3390/polym11081356

[7] S. N. Monteiro, T. L. Milanezi, L. H. L. Louro, É. P. Lima, F. O. Braga, A. V. Gomes e J. W. Drelich, "Novel ballistic ramie fabric composite competing with Kevlar™ fabric in multilayered armor," Materials & Design, vol. 96, pp. 263-269, 2016. https://doi.org/10.1016/j.matdes.2016.02.024

[8] F. d. O. Braga, L. T. Bolzan, F. S. d. Luz, P. H. L. M. Lopes, É. P. L. Jr. e S. N. Monteiro, "High energy ballistic and fracture comparison between multilayered armor systems using non-woven curaua fabric composites and aramid laminates," Journal of Materials Research and Technology, vol. 6, nº 4, pp. 417-422, 2017. https://doi.org/10.1016/j.jmrt.2017.08.001

[9] S. N. Monteiro, L. H. L. Louro, W. Trindade, C. N. Elias, C. L. Ferreira, E. de Sousa Lima, R. P. Weber, J. C. Miguez Suarez, A. B.-H. da Silva Figueiredo, W. A. Pinheiro, L. C. da Silva e É. P. Lima, "Natural Curaua Fiber-Reinforced Composites in Multilayered Ballistic Armor," Metallurgical and Materials Transactions A, vol. 46, p. 4567-4577, 2015. https://doi.org/10.1007/s11661-015-3032-z

[10] R. Cruz, É. Jr, S. Monteiro e L. Louro, "Giant Bamboo Fiber Reinforced Epoxy Composite in Multilayered Ballistic Armor," Materials Research, vol. 18, p. 70 - 75, 2015. https://doi.org/10.1590/1516-1439.347514

[11] L. &. M. F. &. M. S. &. V. C. M. &. A. B. &. S. L. E. Rohen, "Ballistic Efficiency of an Individual Epoxy Composite Reinforced with Sisal Fibers in Multilayered Armor," Materials Research, vol. 18, p. 55 - 62. https://doi.org/10.1590/1516-1439.346314

[12] F. &. J. É. &. L. L. &. M. S. Luz, "Ballistic Test of Multilayered Armor with Intermediate Epoxy Composite Reinforced with Jute Fabric," Materials Research, vol. 18, p. 170 - 177, 2015. https://doi.org/10.1590/1516-1439.358914

[13] L. &. L. L. &. M. S. &. G. A. &. M. R. &. J. É. &. M. J. Nascimento, "Ballistic Performance of Mallow and Jute Natural Fabrics Reinforced Epoxy Composites in Multilayered Armor," Materials Research, vol. 20, p. 399 - 403, 2017. https://doi.org/10.1590/1980-5373-mr-2016-0927

[14] F. &. M. T. &. M. S. &. L. L. &. G. A. &. J. É. de Oliveira Braga, "Ballistic comparison between epoxy-ramie and epoxy-aramid composites in Multilayered Armor Systems," Journal of Materials Research and Technology, vol. 7, p. 541 - 549, 2018. https://doi.org/10.1016/j.jmrt.2018.06.018

[15] S. &. P. A. &. F. C. &. J. É. Monteiro, "Performance of Plain Woven Jute Fabric-Reinforced Polyester Matrix Composite in Multilayered Ballistic System," Polymers, vol. 10, nº 3, p. 230. https://doi.org/10.3390/polym10030230

[16] M. S. Oliveira, A. C. Pereira, F. d. C. G. Filho, F. S. d. Luz, F. d. O. Braga, L. F. C. Nascimento, É. P. LimaJr, L. C. d. C. Demosthenes e S. N. Monteiro, "Fique Fiber-Reinforced Epoxy Composite for Ballistic Armor Against 7.62 mm Ammunition," em Green Materials Engineering, 2019, p. 193-199. https://doi.org/10.1007/978-3-030-10383-5_22

[17] M. &. V. A. Lu, "Effects of water immersion ageing on composites made of non-dry flax fibres," Materials Today: Proceedings, vol. 31, 2019. https://doi.org/10.1016/j.matpr.2019.11.061

[18] K. Bilisik, "Impact-resistant fabrics (ballistic/stabbing/slashing/spike)," em Engineering of High-Performance Textiles, Elsevier Limited-Woodhead Publishing, 2018. https://doi.org/10.1016/B978-0-08-101273-4.00014-7

[19] S. Morsch, Y. Liu, S. B. Lyon, S. R. Gibbon, B. Gabriele, M. Malanin e K.-J. Eichhorn, "Examining the early stages of thermal oxidative degradation in epoxy-amine resins," Polymer Degradation and Stability, vol. 176, p. 109147, 2020. https://doi.org/10.1016/j.polymdegradstab.2020.109147

[20] H. Yue, J. C. Rubalcaba, Y. Cui, J. P. Fernández-Blázquez, C. Yang e P. S. Shuttleworth, "Determination of cross-sectional area of natural plant fibres and fibre failure analysis by in situ SEM observation during microtensile tests," Cellulose, vol. 26, p. 4693-4706, 2019. https://doi.org/10.1007/s10570-019-02428-7

[21] G. A. Díaz-Ramírez, H. G. Sanchez e R. A. Cruz, "Correlation between cross sectional area and torsion degree of fique yarns by image analysis system," Correlation between cross sectional area and torsion degree of fique yarns by image analysis system, p. 1247, 2019. https://doi.org/10.1088/1742-6596/1247/1/012030

[22] S. N. Monteiro, F. S. d. Assis, C. L. Ferreira, N. T. Simonassi, R. P. Weber, M. S. Oliveira, H. A. Colorado e A. C. Pereira, "Fique Fabric: A Promising Reinforcement for Polymer Composites," Polymers, vol. 10, nº 3, p. 246, 2018. https://doi.org/10.3390/polym10030246

[23] S. S. Morye, P. J. Hine, R. A. Duckett, D. J. Carr e I. M. Ward, "Modelling of the energy absorption by polymer composites upon ballistic impact," Composites Science and Technology, vol. 60, nº 14, pp. 2631-2642, 2000. https://doi.org/10.1016/S0266-3538(00)00139-1

[24] M. S. Oliveira, F. S. d. Luz, H. A. C. Lopera, L. F. C. Nascimento, F. d. C. Garcia Filho e S. N. Monteiro, "Energy Absorption and Limit Velocity of Epoxy Composites Incorporated with Fique Fabric as Ballistic Armor - A Brief Report," Polymers, vol. 13, nº 16, p. 2727, 2021. https://doi.org/10.3390/polym13162727

[25] R. H. M. Reis, L. F. Nunes, F. S. d. Luz, V. S. Candido, A. C. R. d. Silva e S. N. Monteiro, "Ballistic Performance of Guaruman Fiber Composites in Multilayered Armor System and as Single Target," Polymers, vol. 13, nº 8, p. 1203, 2021. https://doi.org/10.3390/polym13081203

[26] N. M. Meliande, M. S. Oliveira, P. H. P. d. Silveira, R. R. Dias, R. L. S. B. Marçal, S. N. Monteiro e L. F. C. Nascimento, "Curaua-Aramid Hybrid Laminated Composites for Impact pplication: Flexural, Charpy Impact and Elastic Properties," Polymers, vol. 14, nº 18, p. 3749, September 2022. https://doi.org/10.3390/polym14183749

[27] N. M. Meliande, P. H. P. M. d. Silveira, S. N. Monteiro e L. F. C. Nascimento, "Tensile Properties of Curaua-Aramid Hybrid Laminated," Polymers, vol. 14, p. 2588, 2022. https://doi.org/10.3390/polym14132588

[28] M. P. Ribeiro, L. d. M. Neuba, P. H. P. M. d. Silveira, F. S. Luz, A. B.-H. d. S. Figueiredo, S. N. Monteiro e M. O. Moreira, "Mechanical, thermal and ballistic performance of epoxy composites reinforced with Cannabis sativa hemp fabric," Journal of Materials Research and Technology, vol. 12, pp. 221-233, 2021. https://doi.org/10.1016/j.jmrt.2021.02.064

[29] A. Pereira, F. de Assis, F. da Costa Garcia Filho, L. da Cruz Demosthenes, H. Lopera e S. Monteiro, "Ballistic Test of Multilayered Armor with Intermediate Polyester Composite Reinforced with Fique Fabric," em Green Materials Engineering, 2019. https://doi.org/10.1007/978-3-030-10383-5_18

[30] M. S. Oliveira, F. d. C. G. Filho, A. C. Pereira, L. F. Nunes, F. S. d. Luz, F. d. O. Braga, H. A. Colorado e S. N. Monteiro, "Ballistic performance and statistical evaluation of multilayered armor with epoxy-fique fabric composites using the weibull analysis," Journal of Materials Research and Technology, vol. 8, nº 6, pp. 5899-5908, 2019. https://doi.org/10.1016/j.jmrt.2019.09.064

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