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Hybrid vegetable/glass fiber epoxy composites: A systematic review

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Abstract Hybrid composites have been drawing the attention of researchers in the composites field because of their high flexibility to tailor properties through fibers hybridization. The behavior of hybrid composites is dependent on nature, amount, processing parameters, among other parameters, of each reinforcing fiber and polymeric resin. Hybrid glass fiber/vegetable reinforced polymer composites combine the high performance of synthetic fibers with the ecological appeal of vegetable ones. When properly hybridized, the resulting properties can be satisfactory. This paper presents a systematic review of hybrid composites using glass fiber and vegetal fiber focusing on reports published in the last five years. The investigation follows PRISMA protocol, which delivers an accurate summary of all available primary research in response to a research question. After inclusion/exclusion steps, 52 papers were included in the review. The presented results focus on thermal, mechanical, and dynamic mechanical properties of hybrid composites. In brief, this methodology helps identifying the main gaps in the literature on hybrid vegetable/glass fiber epoxy composite laminates.

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1. Introduction

Nowadays, the increasing pressure about the preservation of natural resources and political awareness on exploring green alternatives to decreasing global fossil fuel emission (1). Vegetable fibers arise from natural resources and they fulfill the renewability and marketing apse requirements. In the last four decades, thermoset composites with vegetable fibers have been extensively studied are mainly applied in the automotive interior components (2). There is an increasing demand for applying natural composites in other areas, such as in civil structures due to their low density, good processability, low abrasion, and high resistance to corrosion (3). However, the application is restricted to low-medium components and they cannot yet substitute com synthetic fiber composites, such as glass fiber structures. Seeking at minimizing these drawbacks and aiming to broaden the range of applications, there are increasing studies in hybrid synthetic/vegetable fiber-reinforced composites. When the fibers are adequately combined, the resulting properties can be comparable to pure synthetic fiber composite and hence replace synthetic fibers, depending upon the application (4–10).

Hybrid composites are tailorable materials, which are driven by the role of fibers arrangement in the composite system. The behavior of hybrid composites considers the contribution of each reinforcing phase (the type of reinforcement, geometry, etc.), in which the composite can be manufactured aiming at taking the best characteristics of each fiber. There are innumerous studies regarding glass/vegetable hybrid composites that can be found in the literature in different databases (4,10–12). Often, the chosen research topic is not immediately found in the performed searches, and when a review on this particular chosen topic is carried out, several times, it is identified that previous studies on the same topic have already been done, invalidating the approach. In this context, a systematic review is a powerful tool that helps the readers to rapidly find the lacks and most studied topics of a specific subject.

2. Systematic review

Different than a conventional literature review, a systematic review aims to *identify, evaluate, and summarize the findings of all relevant individual studies* over a defined issue, *making the available evidence more accessible to decision-makers* (13). Primarily, the protocol is employed based on a severe and rigorous scientific search allowing anticipate potential problems and indicating gaps in knowledge, which can be used as a starting point for developing new researches. An important characteristic is that some granting agencies require a systematic review to justify the planned research (14). Another important characteristic is preventing arbitrary decisions (by respecting inclusion criteria and extraction of data), then, it follows a protocol.

Systematic reviews are very widespread in the area of medicine and health care. Some systematic reviews were published regarding low health literacy and health outcomes (15), insomnia, complementary medicine (16), and renal cancer (17). In the polymeric fields, very few studies were released following the PRISMA protocol (18,19). However, until now, in the composites field, there is no systematic review that follows PRISMA methodology focusing on their mechanical, thermal, and dynamic mechanical properties, especially when it comes to vegetable fibers/cellulose chemically modified/epoxy composites.

Hence, the main aim of this book chapter is to compile data between 2016 and 2020, about composite laminates with epoxy resin as matrix and hybrid glass/vegetable fibers as the reinforcing phase. We focus on thermal, mechanical, and dynamic mechanical properties, as well as the manufacturing process to verify a future trend or gaps in this area. Moreover, we list the obtained data regarding the reinforcement type and processing method.

3. Systematic review methodology

The methodological guidelines outline the Transparent Reporting of Systematic Reviews and Meta-Analyses (PRISMA)[1] in which a determined protocol is followed before carrying out this systematic review. This protocol aims to rationale, hypothesize, and plan the review, being a guide. In this book chapter, three different literature databases are considered, and only research papers focused on recent studies in glass/vegetable fiber hybrid composites using epoxy resin as a matrix are taken into consideration. More details are presented next.

Papers are selected using Scopus (www.scopus.com), Web of Science (www.webofknowledge.com), and SciFinder (https://sso.cas.org/) databases. The terms of search are: ([epoxy] AND [hybrid] AND [composites] AND [natural] AND [glass] AND [fiber]). We choose the word "natural" instead "vegetable" because no paper was found with this term, despite being a well-accepted term in the field. The results are limited to papers published from 2016 to 2020. The identified articles have their titles and abstracts assessed independently by two reviewers (Neves, R.M., and Ornaghi Jr, H.L.) to screen their allocation in the systematic review.

This book chapter focuses on recent studies in the hybrid glass/vegetable fiber composites field. The type of vegetal fiber, manufacturing process, and thermal, mechanical, and dynamic mechanical properties are listed excluding microscopies (e.g. scanning electron microscopy - SEM, and optical microscopy) and chemical analyzes (e.g., FTIR, XRD, NMR) as well other results such as flammability, aging, wettability, and water absorption.

4. Results of data collection

The study selection can be better visualized in the flowchart (Fig. 1.), in which the records for every database are identified as well the exclusion criteria and selected papers by eligibility. The total search is of 285 studies, including all chosen databases. In this step, conference papers, review studies, studies not presented in English language, book chapter, editorial, letters, and notes are not considered. With only research papers remaining, some studies which do not account for the present systematic review methodology are excluded: studies with other matrices other than epoxy resin (12 studies), no hybrid composites (7 studies), hybrid composites other than epoxy glass/fiber/vegetable fibers (14 studies), hybrid composites with epoxy matrix but without vegetable fibers as reinforcement (15), vegetable hybrid composites with epoxy matrix but without glass fiber as reinforcement (67), and composites that add another material as a third component (38) are excluded. After this step, 132 studies remained. From these, 84 are excluded for duplicity on the databases. After all, 48 meet all selected criteria, then composing the current systematic review.

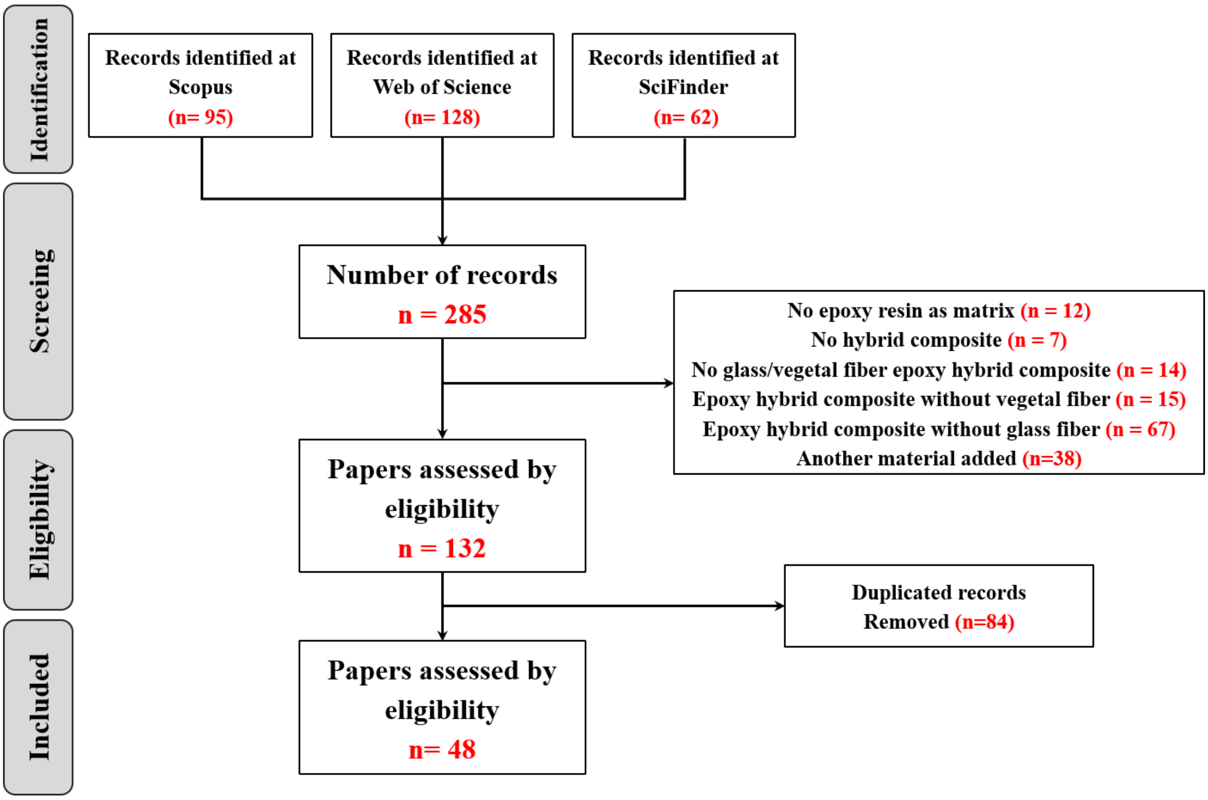

Fig. 1. Systematic review flowchart following PRISMA protocol.

The type of glass fiber (chopped, unidirectional, and woven), natural fiber (chopped, continuous mat, woven, and powder), and composite are presented in Fig. 2. Highlighting the frequency of appearance in the selected research papers.

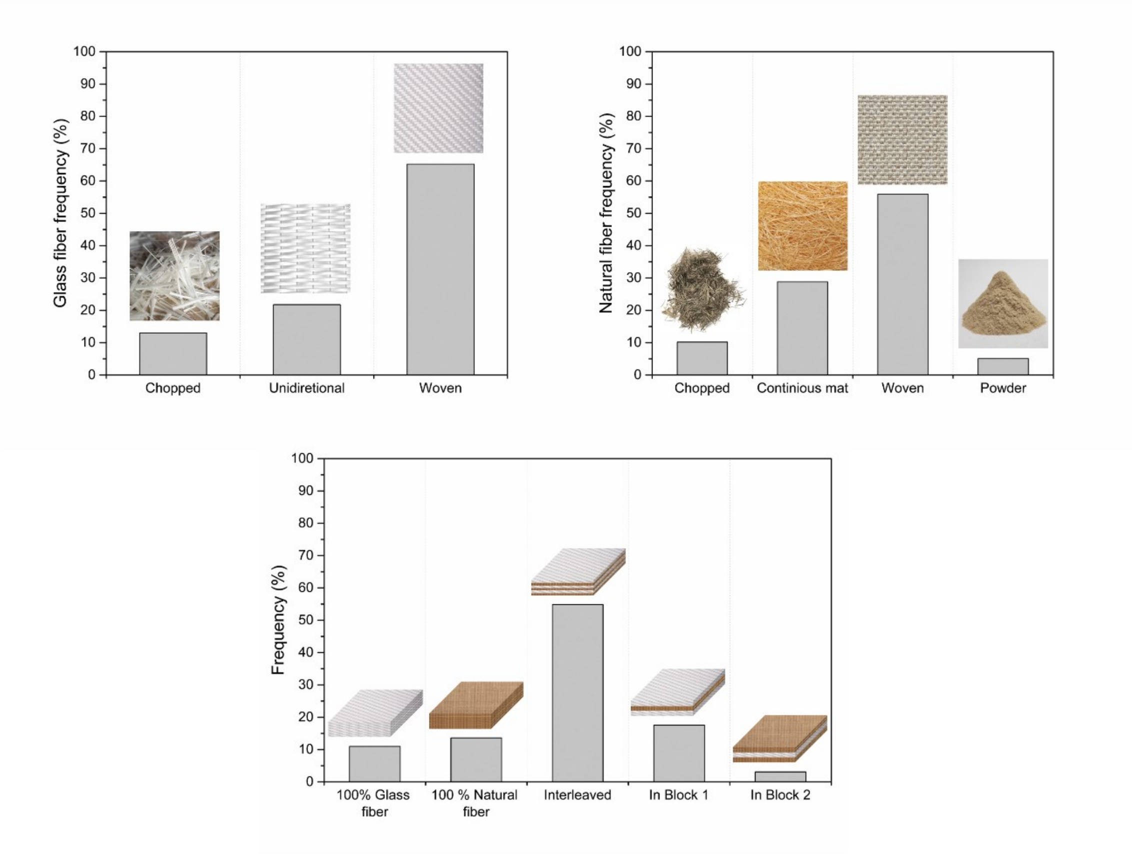

Fig. 2. Frequency of the glass fibers, natural fiber, and type of composites found on the Systematic review.

5. Results and discussion

Table 1 presents all results of the 48 selected papers according to PRISMA flowchart (Fig. 1.) summarized in the systematic review search. The type of fiber, processing manufacturing, and the description of thermal, mechanical, and dynamic mechanical properties are described in Table 1.

Table 1. Thermal, mechanical, and dynamic-mechanical properties of the hybrid composites.

Abbreviations:

X_t = tensile strength; X_b: bending strength; X_c: compressive strength; I_{Izod}: Izod impact strength; EA: Energy absorption; F_t: maximum tensile force; E_t: tensile modulus; E_c: compressive modulus; E_b: bending modulus; SBS: short beam strength; S: in-plane shear strength; G: shear modulus; ν: Poisson's ratio

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	Mechanical	Dynamic-Mechanical E': glassy region
(20)	Interleaved Hygrothermaly aged Pineapple leaf fiber (PALF)/glass (G): **Dry** (non-aged); **Wet** (aged) **i.** 4P **ii.** PGPG **iii.** PGGP **iv.** GPPG	PALF (P)	Hot compression molding	--	Tensile results: **Dry** X_t (MPa): **i.** 47.1; **ii.** 62.6; **iii:** 68.0; **iv:** 119.2 **Wet** X_t (MPa): **i.** 32.0; **ii.** 35.3; **iii:** 42.8; **iv:** 58.8 **Dry** E_t (GPa): **i.** 3.0; **ii.** 4.1; **iii:** 3.2; **iv:** 5.1 **Wet** E_t (GPa): **i.** 1.9; **ii.** 2.8; **iii:** 3.1; **iv:** 2.2 3-point bending results: **Dry** X_b (MPa): **i.** 78.1; **ii.** 124.6; **iii:** 130.4; **iv:** 170.7 **Wet** X_b (MPa): **i.** 58.3; **ii.** 96.1; **iii:** 83.6; **iv:** 94.9 **Dry** E_b (GPa): **i.** 2.9; **ii.** 4.4; **iii:** 2.1; **iv:** 3.3 **Wet** E_b (GPa): **i.** 1.2; **ii.** 1.4; **iii:** 1.2; **iv:** 1.6	--
(21)	Interleaved Banana/Glass (G):	Banana (B)	Hand lay-up	--	3-point bending results:	**--**

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	Mechanical	Dynamic-Mechanical E': glassy region
	i. G8 **ii.** G4B1G3 **iii.** G3B2G3 **iv.** G3B3G2				X_b (MPa): **i.** 430; **ii.** 470; **iii:** 350; **iv:** 270	
(22)	Interleaved Calotropis Procera (CP)/glass (G)/epoxy (E) **i.** 0/0/100 CP/G/E **ii.** 20/0/80 CP/G/E **iii.** 15/5/80 CP/G/E **iv.** 10/10/80 CP/G/E **v.** 5/15/80 CP/G/E **vi.** 0/20/80 CP/G/E	Calotropis Procera (CP)	Hand lay-up	--	**X_t:** **i.** 35 MPa **ii.** 37 MPa **iii.** 42 MPa **iv.** 46 MPa **v.** 47 MPa **vi**. 53 MPa **E_t:** **i.** 1351 MPa **ii.** 1896 MPa **iii.** 2364 MPa **iv.** 2626 MPa **v.** 2763 MPa **vi**. 2983 MPa	**i.** 2243 MPa **ii.** 2533 MPa **iii.** 2878 MPa **iv.** 2954 MPa **v.** 3102 MPa **vi**. 3151 MPa @40 °C
(23)	Interleaved Flax (F)/Glass (G): **Aged** and **non-aged**: i. FFFFFFFF ii. FGGGGGGF iii. FFGGGGFF iv. FFFGGFFF	Flax (F)	Hand lay-up	--	3-point bending results: **Non-aged**: **i.** 22 GPa; **ii.** 24 GPa; **iii.** 22 GPa; **iv.** 22 GPa; **v.** 33 GPa; **vi.** 41 GPa; **vii.** 52 GPa **Aged**: **i.** 10 GPa; **ii.** 18 GPa; **iii.** 13 GPa; **iv.** 12 GPa; **v.** 26 GPa; **vi.** 38 GPa; **vii.** 48 GPa	--

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	Mechanical	Dynamic-Mechanical E': glassy region
	v. GFFFFFFG vi. GGFFFFGG vii. GGGFFGGG viii. GGGGGGGG					
(24)	Interleaved Sisal (S)/Glass (G) **i.** $[G]_{12}$ **ii.** $[S]_{12}$ **iii.** $[G/S]_6$	Sisal	Hand lay-up	--	3-point bending results: **i.** 788 MPa; **ii.** 107 MPa; **iii.** 365 MPa	--
(25)	Interleaved Flax (F)/Glass (G): **Aged** in salt fog. Samples with circular holes with 4, 8, and 10 mm. **i.** GFA (non-aged); **ii.** GFB (30 days aging); **iii.** GFC (60 days aging)	Flax (F)	Vacuum-assisted resin infusion	--	Maximum bearing stress: **D = 4 mm**: **i.** 200 MPa; **ii.** 164 MPa; **iii.** 157 MPa **D = 8 mm**: **i.** 180 MPa; **ii.** 175 MPa; **iii.** 152 MPa **D = 10 mm**: **i.** 159 MPa; **ii.** 125 MPa; **iii.** 107 MPa	--
(26)	Interleaved Mustard cake powder (M)/Glass (G)/epoxy/E) **i.** 0/40/60 (M/G/E); **ii.** 10/40/50 (M/G/E);	Mustard cake powder (M)	Hand lay-up	--	X_t (MPa): **i.** 28; **ii.** 35; **iii:** 90; **iv:** 97; **v.** 110; **vi.** 135 X_b (MPa): **i.** 164; **ii.** 251; **iii:** 172; **iv:** 313; **v.** 192; **vi.** 538 SBS (MPa): **i.** 1.7; **ii.** 2.0; **iii:** 2.5; **iv:** 2.6; **v.** 2.9; **vi.** 3.1	--

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	Mechanical	Dynamic-Mechanical E': glassy region
	iii. 0/60/40 (M/G/E); **iv.** 10/50/50 (M/G/E); **v.** 0/80/20 (M/G/E); **vi.** 10/80/10 (M/G/E);					
(27)	Interleaved Pine apple (PA)/Glass (G): **i.** GPPP; **ii.** GGPP; **iii.** GGGP; **iv.** GGGG; **v.** PPPP	**PINE APPLE (PA)**	**HAND LAY-UP**	**--**	X_t (MPa): **i.** 130; **ii.** 144; **iii:** 168; **iv:** 194; **v.** 115 X_c (MPa): **i.** 98; **ii.** 115; **iii:** 138; **iv:** 175; **v.** 87 X_b (MPa): **i.** 115; **ii.** 132; **iii:** 141; **iv:** 131; **v.** 102 I (J/m): **i.** 260; **ii.** 345; **iii:** 379; **iv:** 411; **v.** 214	--
(28)	Interleaved Jute (J)/Glass (G): **i.** J6; **ii.** G6; **iii.** GJ4G; **iv.** JG4J; **v.** CJ4C; **vi.** CGGGGC; **vii.** JGCCGJ; **viii.** CGJJGC; **ix.** CCGGJJ	Jute (J)	Hand lay-up	--	S (MPa): **i.** 23; **ii.** 61; **iii:** 31; **iv:** 56; **v.** 27; **vi.** 63; **vii.** 52 ; **viii.** 51; **ix.** 51 G (GPa): **i.** 0.8; **ii.** 2.8; **iii:** 1.2; **iv:** 2.7; **v.** 0.9; **vi.** 3.7; **vii.** 1.0 ; **viii.** 1.7; **ix.** 1.3	--
(29)	Interleaved Jute(J)/Glass(G) and Flax (F)/Glass (G)	Jute (J) and Flax (F)	Hand lay-up	**--**	X_t (MPa): **i.** 47; **ii.** 70; **iii:** 76; **iv:** 127 E_t (GPa): **i.** 4.9; **ii.** 6.8; **iii:** 4.6; **iv:** 4.0	--

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	Mechanical	Dynamic-Mechanical E': glassy region
	i. J4; **ii.** GJJG; **iii.** FFFFFFFF; **iv.** GGFFFFGG					
(30)	Interleaved Cotton /G)/Glass (G): V_f = 20%: **i.** C; **ii.** G; **iii.** C/G; V_f = 30%: **iv.** C; **v.** G; **vi.** C/G	Cotton (C)	Hand lay-up	--	X_t (MPa): **i.** 45; **ii.** 82; **iii:** 84 **iv:** 57; **v.** 87; **vi.** 90 X_b (MPa): **i.** 52; **ii.** 60; **iii:** 67; **iv:** 64; **v.** 70; **vi.** 72 I (J/m^2): **i.** 80; **ii.** 141; **iii:** 145; **iv:** 98; **v.** 182; **vi. 1**90	--
(31)	Unidirectional Flass (F)/Glass (G): **i.** [0_{G2}/0_{F12}/ 0_{G2}]; **ii.** [0_{G2} ±45_{F12}/0_{G2}]	Flax (F)	Hot compressio n	--	X_c (MPa): **i.** 262; **ii.** 232 E_c (GPa): **i.** 24; **ii.** 15 ν: **i.** 0.37; **ii.** 0.58 Fatigue: E_0^*: **i.** 15 (7% loss); **ii.** 10 (0% loss)	--
(32)	Interleaved Kenaf (K)/Glass (G): **i.** 100% G; **ii**. 100% K; **iii**. 25% GF + 75% KF; **iv.** 30% GF + 70% KF; **v.** 50% GF + 50% KF; **vi**. 70% GF + 30% KF; **vii**. 75% GF + 25% KF	Kenaf (K)	Hand lay-up	--	F_t (kN): **i.** 46; **ii.** 11; **iii:** 14 **iv:** 19; **v.** 26; **vi.** 33; **vii.** 37	--
(33)	Interleaved Jute (J)/Glass (G): **i.**	Jute (J)	Hand lay-up	--	X_t (MPa): **i.** 143; **ii.** 283; **iii:** 329 **iv:** 428	--

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	Mechanical	Dynamic-Mechanical E': glassy region
	Jute/epoxy; **ii**. 45:55 J:G; **iii**. 30:70 J/G; **iv**. Glass/Epoxy				E_t (GPa): **i.** 8; **ii.** 12; **iii:** 13; **iv:** 16	
(34)	Interleaved Jute (J)/Kenaf (K)/Glass (G): **i**. GGGGG; **ii**. JJJJJ; **iii**. KKKKK; **iv**. JKJKJ; **v.** KJKJK; **vi**. GJJJG; **vii**. GKKKG; **viii.** GJKJG; **ix**. GKJKG	Jute (J) and kenaf (K)	Vacuum bagging	--	I_{Izod} (J/m): **i**. 1469; **ii**. 122; **iii**. 152; **iv**. 134; **v.** 171; **vi**. 792; **vii**. 897; **viii.** 860; **ix**. 1078 SBS (MPa): **i**. 18; **ii**. 5; **iii**. 6; **iv**. 5; **v**. 6; **vi**. 8; **vii**. 11; **viii.** 9; **ix**. 13	--
(35)	Interleaved Flax /(F)/Glass (G) **Aged** in salt fog for: **0 days**: **i.** $[G]_{16}$; **ii.** $[F]_{10}$; **iii.** $[G_3/F_3]_s$; **30 days**: **iv.** $[G]_{16}$; **v.** $[F]_{10}$; **vi.** $[G_3/F_3]_s$; **60 days**: **vii.** $[G]_{16}$; **viii.** $[F]_{10}$; **ix.** $[G_3/F_3]_s$	Flax (F)	Vacuum assisted resin infusion method	T_g (°C): **i.** 82; **ii.** 80; **iii.** 80, **iv.** 82; **v.** 82; **vi.** 80, **vii.** 83; **viii.** 80; **ix.** 80	X_b (MPa): **i.** 397; **ii.** 113; **iii.** 212, **iv.** 342; **v.** 82; **vi.** 159, **vii.** 317; **viii.** 36; **ix.** 144_s E_b (MPa): **i.** 17; **ii.** 4; **iii.** 9, **iv.** 16; **v.** 2; **vi.** 7, **vii.** 16; **viii.** 2; **ix.** 6	E' (GPa): **i.** 12.0; **ii.** 4.2; **iii.** 6.3, **iv.** 11.4; **v.** 2.5; **vi.** 4.2, **vii.** 9.6; **viii.** 2.4; **ix.** 3.8

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	**Mechanical**	**Dynamic-Mechanical E’: glassy region**
(36)	Interleaved unidirectional Neem (N)/Kenaf (K)/Glass (G): **i**. GNKNG_90°; **ii**. GNKNG_0°	Neem (N) and Kenaf (K)	Hand lay-up	--	X_t (MPa): **i**. 33; **ii**. 31 X_c (MPa): **i**. 43; **ii**. 37	--
(37)	Date palm seed (DS) filler/Glass (G) – Percentage of filler in glasss/epoxy composite: 5 w.t.%: **i**. SiC; **ii**. Al_2O_3; **iii**. DS 10 w.t.%: **iv**. SiC; **v**. Al_2O_3; **vi**. DS	Date palm seed (DS)	Semi hand lay-up	--	Wear rate: **i**. 4.5; **ii**. 2.1; **iii**. 2.5; **iv**. 8.2; **v**. 6.8; **vi**. 7.3	--
(38)	Intraply filament wound kenaf (K)/glass (G) tubes at 30°, 45°, 70°: Hybrid K/G: **i**. $[\pm30]_6$; **ii**. $[\pm45]_6$; **iii**. $[\pm70]_6$ Non-hybrid (glass): **iv**. $[\pm30]_9$;	kenaf (K)	Filament winding	--	EA (J) in axial crushing test: **i**. 1780; **ii**. 2912; **iii**. 3695Non-hybrid (glass): **iv**. 1588; **v**. 1734; **vi**. 1852	

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	Mechanical	Dynamic-Mechanical E': glassy region
(39)	**v**. [±45]$_9$; **vi**. [±70]$_9$					
(39)	Interleaved aged flax (F)/sisal(S)/glass(G): Without treatment **i**. GFG-UT; **ii**. GSG-UT; **iii**. SGF-UT With alkali NaOH treatmen: **iv**. GFG-T; **v**. GSG-T; **vi**. SGF-T	flax (F) and sisal(S)	Hand lay-up	T_d (°C): **i.** 316; **ii.** 313; **iii:** 312; **iv:** 313; **v.** 317; **vi**. 307	X_t (MPa): **i.** 53; **ii.** 62; **iii:** 30; **iv:** 96; **v.** 69; **vi**. 46; X_b (MPa): **i.** 155; **ii.** 189; **iii:** 96; **iv:** 224; **v.** 188; **vi**. 198 I (J/m): **i.** 13; **ii.** 17; **iii:** 13; **iv:** 22; **v.** 18; **vi**. 20	--
(40)	Interleaved chemically treated Tea particulate (T)/pineapple fiber (P)/glass(G): stacking sequence: GPGTGPG with different weight fraction: **i.** 5:25:10 (T:P:G); **ii.** 10:20:10 (T:P:G); **iii.**	Chemically treated Tea particulate (T)/pineapple fiber (P)	Hot compression molding	--	X_t (MPa): **i.** 36; **ii.** 43; **iii:** 39; **iv:** 38; **v.** 71 E_t (GPa): **i.** 5.5; **ii.** 6.2; **iii:** 5.6; **iv:** 5.4; **v.** 22.6 X_b (MPa): **i.** 430; **ii.** 451; **iii:** 481; **iv:** 295; **v.** 422 I_{Izod} (J): **i.** 122; **ii.** 128; **iii:** 122; **iv:** 102; **v.** 104 SBS (MPa)**: i.** 87; **ii.** 86; **iii:** 79; **iv:** 83; **v.** 87	--

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	Mechanical	Dynamic-Mechanical E': glassy region
	15:15:10 (T:P:G); **iv.** 20:10:10 (T:P:G); **v.** 25:5:10 (T:P:G)					
(41)	Interleaved jute (J)/glass (G) with biaxial fabrics at ±45° (45) or 0°/90° (0/90): **i**. GGGGG (G45); **ii**. GJJG (H45); **iii.** GJJG (H0/90); **iv.** GJJG (H45//0/90)	Jute (J)	Vacuum infusion		SBS (MPa): **i.** 26; **ii.** 23; **iii.** 26, **iv.** 21 X_c (MPa): **i.** 121; **ii.** 90; **iii.** 150, **iv.** 90	E' (GPa): **i.** 6959; **ii.** 6043; **iii.** 8347, **iv.** 7186
(42)	Date palm seed filler (DS)/glass (G): **i**. 0 w.t.% DS; **ii**. 5 w.t.% DS; **iii**. 10 w.t.% DS	Date palm seed filler (DS)	Semi hand lay-up	--	X_t (MPa): **i**. 130; **ii**. 170; **iii**. 183 I_{Izod} (MPa): **i**. 1.6; **ii**. 3.7; **iii**. 7.2	
(43)	Interleaved chemically-treated cotton dust waste (CDW)/jute (J) and cotton dust waste (CDW)/glass (G). Untreated (U).	Cotton dust waste (CDW) and jute (J)	Hand lay-up		X_t (MPa): **i**. 42; **ii**. 53; **iii.** 55; **iv.** 59; **v.** 50; **vi.** 40; **vii.** 52; **viii.** 57; **ix.** 61; **x.** 54 E_t (MPa): **i**. 1200; **ii**. 2042; **iii.** 1945; **iv.** 1773; **v.** 1520; **vi.** 808; **vii.** 1368; **viii.** 1420; **ix.** 1472; **x.** 1550 X_b (MPa): **i**. 86; **ii**. 109; **iii.** 111 **iv.** 121; **v.** 113; **vi.** 84; **vii.** 104; **viii.** 108; **ix.** 122; **x.** 110	

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	Mechanical	Dynamic-Mechanical E': glassy region
	i. 20UCDW15G; **ii**. 10CDW25G; **iii.** 15CDW20G; **iv.** 20CDW15G; **v.** 25CDW10G; **vi.** 20UCDW15UJ; **vii.** 10CDW25J; **viii.** 15CDW20J; **ix.** 20CDW15J; **x.** 25CDW10J				E_b (MPa): **i**. 1819; **ii**. 2930; **iii.** 2910; **iv.** 2890; **v.** 3346; **vi.** 1700; **vii.** 3267; **viii.** 2958; **ix.** 2658; **x.** 2776 I_{Charpy} (J): **i.** 6.5; **ii**. 14.5; **iii.** 13.3; **iv.** 12.2; **v.** 10.5; **vi.** 5.7; **vii.** 8.2; **viii.** 8.5; **ix.** 8.8; **x.** 9.5	
(44)	Interleaved composites (Woven E-glass – G): G:R:A:R:A:R:G	Woven aloevera fiber (A) Woven roselle fiber (R)	Hand lay-up	-	Tensile test: Xt (MPa): 38.6 E_t (GPa): 0.8 ε (%): 5.4 Flexural test: Xt (MPa): 5.9 E_b (GPa): 0.13 ε (mm): 4.6 Izod impact test: I (J): 5.6	-
(45)	Interleaved composites (Woven E-glass – G): i - H:G $[(0/90)^H/G/(45)^H]_s$ ii - F:G $[(0/90)^F/G/(45)^F]_s$	Flax (F) Ham fiber (H)	Hand lay-up	-	Flexural test: Xt (MPa): **i** – 88.3; **ii** – 18; **iii** – 86.3 Hardness test: H (Rockwell): **i** – 92.6; **ii** – 90.6; **iii** – 94.8	-

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	**Mechanical**	**Dynamic-Mechanical E': glassy region**
	iii – F:H:G $[(90)^{F}/G/(45)^{H}]_{s}$					
(46)	Interleaved composites (NCF E-glass – G): **i -** G:K:G (70/30) **ii -** K:G:K (35/65) 40% of fiber content for all laminates	Plain weave Kenaf fabric (K)	VARTM	-	Tensile test: Xt (MPa): **i** – 55.1; **ii** – 48.0; E (GPa): **i** – 7.5; **ii** – 6.5 ε (%): **i** – 1.2; **ii** – 1.0 Fatigue test: **i** – Xt = 50.9 $N^{-0.47}$ **ii** – Xt = 58.4 $N^{-0.66}$	-
(47)	Interleaved composites (Woven E-glass – G): **i** - Glass **ii** - G:J	Jute (J)	VARTM	TGA: First degradation (ºC): **i** – 322.8; **ii** – 325 Second degradation (ºC): **i** – 400.2; **ii** – 405.7 Residue (%): **i** – 44.5; **ii** – 42.1	-	-
(48)	Interleaved composites (chopped fibreglass mats – G): **i** - Jute **ii** - G:J (25/75) **iii** - G:J (50/50) **iv** - G:J (75/25) **v** - Glass	Jute (J) Bagasse (B)	Hand lay-up	-	Tensile test: Xt (MPa): **i** – 40; **ii** – 60; **iii** – 62; **iv** – 70; **v** – 80; **vi** – 35; **vii** – 30; **viii** – 16 Hardeness test: H (Rockwell): **i** – 40; **ii** – 61; **iii** – 66; **iv** – 70; **v** – 80; **vi** – 30; **vii** – 40; **viii** – 25	-

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	Mechanical	Dynamic-Mechanical E': glassy region
	vi - G:B (75/25) **vii** - G:B (50/50) **viii** - G:B (25/75) 40% of fiber content for all laminates					
(49)	Interleaved composites (chopped fibreglass mats – G): i - Glass ii - G:CS (80/20) iii - G:CS (60/40) iv - G:CS (40/60) v - G:CS (20/80) vi - CS 25% of fiber content for all laminates	Cotton shell (CS)	Hand lay-up and compression moulding	-	<u>Tensile test:</u> Xt (MPa): **i** – 50.6; **ii** – 55.1; **iii** – 71.8; **iv** – 57.3; **v** – 40.6; **vi** – 20.4 <u>Flexural test:</u> Xt (MPa): **i** – 100.2; **ii** – 112.3; **iii** – 123.8; **iv** – 103.0; **v** – 80.1; **vi** – 66.7 <u>Compressive test:</u> Xt (MPa): **i** – 85.8; **ii** – 99.8; **iii** – 115.2; **iv** – 105.4; **v** – 90.7; **vi** – 84.9 <u>Hardness test:</u> H (Brinell): **i** – 38; **ii** – 40; **iii** – 44; **iv** – 41; **v** – 36; **vi** – 34 <u>Izod impact test:</u> I (J): **i** – 5; **ii** – 6; **iii** – 8; **iv** – 6; **v** – 4; **vi** – 3	-
(50)	Interleaved composites (E-glass fabric – G):	Pennisetum purpureu	VARTM	-	<u>Tensile test:</u> Xt (MPa): **i** – 130; **ii** – 100; **iii** – 75; **iv** – 46; **v** – 32	-

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	**Mechanical**	**Dynamic-Mechanical E': glassy region**
	i - G:PP (80/20) ii - G:PP (60/40) iii - G:PP (20/80) iv - G:PP (20/80) v – PP 30% of fiber content for all laminates	m fiber (PP)			E (GPa): **i** – 6.0; **ii** – 5.8; **iii** – 5.8; **iv** – 3.5; **v** – 3.0 Flexural test: Xt (MPa): **i** – 120; **ii** – 108; **iii** – 76; **iv** – 70; **v** – 52 E (GPa): **i** – 12.0; **ii** – 10.7; **iii** – 8.2; **iv** – 5.8; **v** – 3.9	
(51)	composite tubes (glass fiber – G): Cilyndrical **i** - Jute 50mm **ii** - Jute 100mm **iii** - G:J 50mm **iv** - G:J 100mm Square **v** - Jute 50mm **vi** - Jute 100mm **vii** - G:J 50mm **viii** - G:J 100mm [G/J_2]	Jute (J)	Hand lay-up	-	Compression test: EA (kJ): **i** – 0.9; **ii** – 0.6; **iii** – 1.1; **iv** – 0.9; **v** – 0.4; **vi** – 0.1; **vii** – 0.7; **viii** – 0.6 SEA (kJ·kg^{-1}): **i** – 19.0; **ii** – 7.0; **iii** – 21.6; **iv** – 9.0; **v** – 3.5; **vi** – 1.0; **vii** – 8.6; **viii** – 4.6	-
(52)	Interleaved composites (twill glass fabric – G): **i** - Flax **ii** - G:F (85/15) [G/F_4]$_s$ **iii** - G:F (75/25)	2x2 twill flax fabric (F)	Pre-preg compression moulding	-	Tensile acustic emission: Amplitude (dB): **i** – F 60, M 35, D 45; **ii** – F 68, M 33, D 40; **iii** – F 50, M 32, D 39; **iv** – F 72, M 32, D 41; **v** – F 51, M 31, D 37;	-

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	**Mechanical**	**Dynamic-Mechanical E': glassy region**
	$[G_2/F_3]_s$ **iv** - G:F (55/45) $[G_3/F_2]_s$ **v** - G:F (30/70) $[G_4/F]_s$ **vi** - Glass				**vi** – F 70, M 32, D 40 Damage hit contribution (%): **i** – F 49, M 9, D 42; **ii** – F 70, M 1, D 29; **iii** – F 91, M 1, D 8; **iv** – F 68, M 2, D 30; **v** – F 86, M 3, D 10; **vi** – F 78, M 10, D 12 * Fiber failure (F), matrix crack (M), fiber-matrix desbonding (D)	
(53)	Interleaved composites (unidirection fibreglass – G): Horizontal orientation **i** - G:A_3:G **ii** - G:N_3:G **iii** - G:A_3N_3:G Vertical orientation **iv** - G:A_3:G **v** - G:N_3:G **vi** - G:A_3N_3:G 45º orientation **vii** - G:A_3:G **viii** - G:N_3:G	Neem (N) Abaca (A)	Hand lay-up	-	Tensile test: Xt (MPa): **i** - 83; **ii** - 86; **iii** – 91; **iv** – 94; **v** – 92; **vi** – 102; **vii** – 90; **viii** – 100; **ix** – 120 Flexural test: Xt (MPa): **i** – 8; **ii** – 14; **iii** – 16; **iv** – 13; **v** – 16; **vi** – 22; **vii** – 14; **viii** – 23; **ix** – 26 Double shear test: Xt (MPa): **i** – 45; **ii** – 55; **iii** – 80; **iv** – 39; **v** – 50; **vi** – 72; **vii** – 59; **viii** – 40; **ix** – 80 Interdelamination test Xt (MPa): **i** – 5; **ii** – 11;	-

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	Mechanical	Dynamic-Mechanical E': glassy region
	ix - G:A_3N_3:G				**iii** – 17; **iv** – 3; **v** – 8; **vi** – 16; **vii** – 7; **viii** – 9; **ix** – 18 Charpy impact test: I (J): **i** – 10; **ii** – 11; **iii** – 13; **iv** – 11; **v** – 12; **vi** – 14; **vii** – 15; **viii** – 18; **ix** – 20	
(54)	Interleaved composites (unidirection fibreglass – G): **i** - J:G 20% **ii** - J:G 30% **iii** - F:G 20% **iv** - F:G 30% **v** - B:G 20% **vi** - B:G 30% 50/50 (v/v) for all laminates	Jute (J) Banana (B) Flax (F)	Hand lay-up	-	Tribological test: Wear rate 1km ($mm^3 \cdot Nm^{-1}$): **i** – 1.33; **ii** – 1.1; **iii** – 1.38; **iv** – 1.17; **v** – 1.12; **vi** – 0.82 Wear rate 1.5km ($mm^3 \cdot Nm^{-1}$): **i** – 0.97; **ii** – 0.73; **iii** – 1.00; **iv** – 0.81; **v** – 0.87; **vi** – 0.61 Wear rate 2km ($mm^3 \cdot Nm^{-1}$): **i** – 0.75; **ii** – 0.56; **iii** – 0.79; **iv** – 0.62; **v** – 0.68; **vi** – 0.48	-
(55)	Interleaved composites (unidirection fibreglass – G): **i -** Glass **ii -** G:B	Banana (B)	Hand lay-up	-	Tensile test: T (kN): **i** – 57.9; **ii** – 38.9 Xt (MPa): **i** – 498.9; **ii** – 296.7 E (GPa): **i** – 10.8; **ii** – 11.1	-

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	Mechanical	Dynamic-Mechanical E': glassy region
(56)	Interleaved composites (twill glass fabric – G): **i** - Flax **ii** - G:F (85/15) $[G/F_4]_s$ **iii** - G:F (75/25) $[G_2/F_3]_s$ **iv** - G:F (55/45) $[G_3/F_2]_s$ **v** - G:F (30/70) $[G_4/F]_s$ **vi** - Glass	2x2 twill weave flax fabric (F)	Pre-preg compressio n moulding	-	Tensile test: Xt (MPa): **i** – 108.2; **ii** – 140.7; **iii** – 168.1; **iv** – 274.6; **v** – 354.2; **vi** – 489.5 E (GPa): **i** – 13.4; **ii** – 14.5; **iii** – 15.9; **iv** – 20.6; **v** – 24.4; **vi** – 33.2 ε (%): **i** – 1.4; **ii** – 1.5; **iii** – 1.6; **iv** – 1.8; **v** – 1.9; **vi** – 2.11	-
(57)	Interleaved composites (plain weave glass fabric – G): I - Glass ii - G:SC (75/25) iii - G:SC (55/45)	Short coir fiber (SC)	Pre-preg vacuum bag + autoclave	-	Tensile test: Xt (MPa): **i** – 350; **ii** – 220; **iii** – 125 Dynamic vibration test: E (GPa): **i** - 6; **ii** - 16; **iii** - 12	-
(58)	cylindrical composite tubes (glass fiber – G): **i** - Glass (15 layers) **ii** - NS	Woven natural Silk (NS)	Hand lay-up	-	quasi-static compression: T (kN): i – 100; ii – 90; iii – 180 EA (J): i - 2457; ii - 950; iii - 3660 SEA ($kJ.g^{-1}$): i - 85; ii - 31;	-

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	Mechanical	Dynamic-Mechanical E': glassy region
	(15 layers) **iii** - G:NS (3G + 9NS layers)				iii – 130 Crush efficiency (%): i – 43; ii - 13; iii - 51	
(59)	Interleaved composites (E-glass – G): **i** - Glass $[(0/90)_3]_s$ **ii** - Jute $[(0/90)_2]_s$ **iii** - Flax $[(0/90)_2]_s$ **iv** - G:J (60/40) $[(0/90/0)^G/(0)^J]_s$ **v** - J:G (40/60) $[(0)^J/(0/90/0)^G]_s$ **vi** - G:F (60/40) $[(0/90)^G/(0)^F]_s$ **vii** - F:G (60/40) $[(0)^F/(0/90)^G]_s$	Plain weave Jute (J) Plain weave Flax (F)	VARTM	-	<u>Tensile test:</u> T (kN): **i** – 8.1; **ii** – 1.2; **iii** – 1.6; **iv** – 4.5; **v** – 4.4; **vi** – 6.6; **vii** – 6.7 Xt (MPa): **i** – 450; **ii** – 70; **iii** – 95; **iv** – 239; **v** – 233; **vi** – 372; **vii** – 358 E (GPa): **i** – 5920; **ii** – 1392; **iii** – 1489; **iv** – 3012; **v** – 2891; **vi** – 3417; **vii** – 3432 ε (%): **i** – 13.7; **ii** – 8.1; **iii** – 11.3; **iv** – 11.6; **v** – 10.6; **vi** – 13.2; **vii** – 12.5 <u>Flexural test:</u> T (N): **i** – 617; **ii** – 106; **iii** – 101; **iv** – 533; **v** – 329; **vi** – 429; **vii** – 212 Xt (MPa): **i** – 500; **ii** – 95; **iii** – 84; **iv** – 418; **v** – 258; **vi** – 348; **vii** – 171	<u>DMA:</u> E' (MPa): **i** – 7571; **ii** – 3371; **iii** – 3370; **iv** – 6332; **v** – 6554; **vi** – 4245; **vii** – 4510 E" (MPa): **i** – 1020; **ii** – 430; **iii** – 438; **iv** – 890; **v** – 985; **vi** – 543; **vii** – 592 Tan delta: **i** – 0.345; **ii** – 0.391; **iii** – 0.401; **iv** – 0.352; **v** – 0.354; **vi** – 0.325; **vii** – 0.354 Tg (ºC): **i** – 79.5; **ii** – 80.3; **iii** – 82.2; **iv** – 79.4; **v** – 79.9; **vi** – 80.1; **vii** – 77.8

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	**Mechanical**	**Dynamic-Mechanical E': glassy region**
					E (GPa): **i** – 17.3; **ii** – 2.9; **iii** – 1.4; **iv** – 17.7; **v** – 6.5; **vi** – 14.2; **vii** – 5.5 ε (%): **i** – 3.1; **ii** – 3.8; **iii** – 2.4; **iv** – 2.6; **v** – 5.1; **vi** – 2.5; **vii** – 4.1	
(60)	Interleaved composites (E-glass – G): **i** - Glass **ii** - Jute **iii** - Kenaf **iv** - J:K (60/40) **v** - J:K (40/60) **vi** - G:J (60/40) **vii** - G:K (60/40) **viii** - G:J:K (60/25/15) **ix** - G:J:K (60/15/25)	Plain weave Jute (J) Plain weave Kenaf (K)	Hand layup vacuum bag - autoclave	-	Tensile test: Xt (MPa): **i** – 331.8; **ii** – 34.7; **iii** – 45.2; **iv** – 42.9; **v** – 47.4; **vi** – 85.4; **vii** – 101.4; **viii** – 88.5; **ix** – 129.2 E (GPa): **i** – 12.7; **ii** – 1.9; **iii** – 2.4; **iv** – 2.3; **v** – 2.4; **vi** – 5.0; **vii** – 5.4; **viii** – 5.1; **ix** – 5.9 Flexural test: Xt (MPa): **i** – 309.3; **ii** – 170.9; **iii** – 190.1; **iv** – 177.0; **v** – 182.0; **vi** – 198.4; **vii** – 232.8; **viii** – 218.2; **ix** – 235.5 E (GPa): **i** – 18.6; **ii** – 10.6; **iii** – 11.8; **iv** – 10.9; **v** – 11.4; **vi** – 12.3; **vii** – 13.9; **viii** – 13.6; **ix** – 14.3	-

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	Mechanical	Dynamic-Mechanical E': glassy region
					<u>Micro-hardness:</u> H (Vickers): **i** – 24.6; **ii** – 10.5; **iii** – 13.5; **iv** – 11.6; **v** – 15.9; **vi** – 20.1; **vii** – 22.3; **viii** – 22.0; **ix** – 23.2	
(61)	Interleaved composites (chooped fibreglass mats): i – Glass fiber ii – Kenaf iii – Glass:K	Woven Kenaf fabric (K)	VARTM	-	<u>Drop impact test:</u> T for 3J (kN): **i** – 1.4; **ii** – 0.7; **iii** – 1.2 T for 6J (kN): **i** – 2.2; **ii** – 0.7; **iii** – 1.4 T for 9J (kN): **i** – 2.7; **ii** – 0.8; **iii** – 1.5 u for 3J (cm): **i** – 0.5; **ii** – 0.7; **iii** – 0.5 u for 6J (cm): **i** – 0.6; **ii** – 1.2; **iii** – 0.7 u for 9J (cm): **i** – 0.7; **ii** – 1.5; **iii** – 1.0 r for 3J (mm): **i** – 10.8; **ii** – 47.7; **iii** – 25.6 r for 6J (mm): **i** – 12.2; **ii** – 82.6; **iii** – 45.4 r for 9J (mm): **i** – 16.1; **ii** – 100.6; **iii** – 52.9	-

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	**Mechanical**	**Dynamic-Mechanical E': glassy region**
(62)	Interleaved composites (glass – G): **i** - G:S:G **ii** - G:C:G **iii** - G:B:G	Sisal fiber (S) Coir fiber (C) Banana fiber (B)	VARTM	-	Tensile test: T (kN): **i** – 2.81; **ii** – 2.89; **iii** – 2.77 Flexural test: Xt (MPa): **i** – 44.4; **ii** – 87.7; **iii** – 76.6 E (GPa): **i** – 3101.3; **ii** – 130.5; **iii** – 474.8	-
(63)	Interleaved composites (E-glass – G): **i** - G:C **ii** - G:C:G **iii** - G:G:C	Coir fibers mats (C)	Hand layup	-	Tensile test: Xt (MPa): **i** – 41.5; **ii** – 53.8; **iii** – 30.61	-
(64)	E-glass:J	Jute fibers mats (J)	Hand layup	-	Tensile test: Xt (MPa): 48.6 E (GPa): 4.2 Compression test: Xt (MPa): 35.0 E (GPa): 1.0 Flexural test: Xt (MPa): 4.4 E (GPa): 3.1 Izod impact test: I (J): 3.3	-

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	Mechanical	Dynamic-Mechanical E': glassy region
(65)	Interleaved composites (E-glass – G): **i** - G:J (50/50) **ii** - G:J (45/55) **iii** - G:J (40/60) **iv** - G:J (30/70)	Jute chopped fibers (J)	Hand layup method	-	Double shear test: L (kN): **i** – 1.4; **ii** – 1.2; **iii** – 1.1; **iv** – 1.0 u (mm): **i** – 1.1; **ii** – 1.2; **iii** – 1.4; **iv** – 1.7 Mode I delamination: L (kN): **i** – 8.5; **ii** – 8.4; **iii** – 8.1; **iv** – 8.0 u (mm): **i** – 4.2; **ii** – 3.8; **iii** – 3.2; **iv** – 2.9 Hardness test: H (Rockwell C): **i** – 88.2; **ii** – 86.4; **iii** – 81.3; **iv** – 76.2	-
(66)	Interleaved composites (E-glass – G): **i** - B:P:G (25/25/50) **ii** - E-glass **iii** - B **iv** - B:G (30/70) **v** - B:G (40/60) **vi** - B:G (50/50) **vii** - P **viii** - P:G (30/70) **ix** - P:G (40/60) **x** - P:G (50/50)	Banana pseudo stem fiber (B) Pineapple leaf fiber (P)	Hot Compression Method	-	Tensile Loading Test: Xt (MPa): **i** – 66.9; **ii** – 132.3; **iii** – 38.7; **iv** – 52.5; **v** – 54.0; **vi** – 65.9; **vii** – 35.4; **viii** – 52.0; **ix** – 54.0; **x** – 57.5; **xi** – 36.1 E (GPa): **i** – 6.2; **ii** – 11.5; **iii** – 4.6; **iv** – 5.4; **v** – 6.4; **vi** – 6.3; **vii** – 4.7; **viii** – 4.8; **ix** – 6.4; **x** – 6.4; **xi** – 3.7	-

Ref	Hybrid composite type	Natural fiber type	Process	Properties		
				Thermal	Mechanical	Dynamic-Mechanical E’: glassy region
	xi - B:P (50/50)					

5. Conclusion and future perspectives

In this study, a systematic review on glass/vegetable hybrid composites between 2016-2020 was performed. The type of reinforcements and manufacturing processes were included. Thermal, mechanical, and dynamic mechanical properties were also targeted. The systematic review proved to be a useful tool for both young and the experienced researchers as a guideline in a specific(s) subject(s). It easily indicates the trends and lacks in a searched topic. This study showed an enormous lack of thermal and dynamic mechanical properties that can be explored for further research. The main studied aspect is at the mechanical properties point of view, which include impact, flexural, compressive, and tensile tests, independently of the reinforcement. Hand lay-up is the most employed manufacturing process, which is certainly associated to the low cost of this process. Finally, the most employed type of both glass and vegetal fiber was woven fabric, being the interleaved composite the most used. Consequently, the fast and easy identification of studies and the possibility of new combinations of reinforcements/manufacturing processes and tested properties make the systematic review a powerful tool in any scientific field.

Vegetable fibers will be continuously employed, and the studies evaluated here pointed out that there is a growing trend for different reasons given ecological appeal and environmental benefits or combination with synthetic fibers for different applications. The weight reduction, easy formability, low cost and ease-processing are some of the many advantages promoted by the vegetal fibers even when combined with synthetic fibers. As a result, glass/vegetable hybrid composites will keep being applied in interior automotive components to add an eco-friendly character while still meeting design requirements (67). In addition, the possibility to chemically/physically modify vegetable fibers aiming to improve their physical-chemical properties is attractive, although it is still ineffective from the mass production point of view. Other promising applications included load-bearing structural members for application in civil applications, including concrete elements, roofing components, bridges, decks, among many others. Other applications include textile and yarn industries, furniture, housing (door, panels, roofing sheets), sporting goods (tennis racket, snowboarding), window frame, fencing, bicycle frame, mobile cases, insulations, bags, flush door shutters, mirror casing, filling material for upholstery, among others (68).

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