A Review of Natural Fiber Composites for Structural, Infrastructural and Ballistic Applications

P. Siva Sankar and S. B. Singh

Abstract Natural fiber composites are becoming suitable alternative material to replace synthetic fibers like carbon, Kevlar and E-glass. Natural fibers are having the properties of biodegradability, renewability, and low density. Nowadays, researchers are showing interest in natural fibers to draw natural fiber-reinforced composites (NFRC). NFRC is generally used in the construction sector for non loading members and researchers are evaluating the applications of NFRC in load-carrying members of the structural and infrastructural areas. The hybridization of natural fibers and synthetic fibers have good results over the plain natural fiber composites. The main problem with natural fibers is that properties are significantly influenced by the source of fiber, type of fiber, and fiber treatment. This chapter presents the review of natural fiber composites applications in structural, infrastructural, ballistic, and fire resistance wings.

Keywords NFRC · Plant fiber · Hybridization · Fire resistance

1 Introduction

Synthetic fibers are commonly used in different engineered structures due to their high specific stiffness and high specific strength. The fibers like Kevlar, glass and carbon are mainly used in the industries of aircraft and aerospace. Synthetic fibers are reinforced with the polymer type of matrix to provide cushioning for fibers to protect them from the impact loads. The cushioning action of matrix also plays a crucial role in seismic attacks by absorbing the rigid structures vibration energy. There are many benefits with the advanced synthetic composites, even though the public commonly criticizes few issues:

P. Siva Sankar (✉) · S. B. Singh
Department of Civil Engineering, Birla Institute of Technology and Science, Pilani 333031, India
e-mail: p20190444@pilani.bits-pilani.ac.in

S. B. Singh
e-mail: sbsingh@pilani.bits-pilani.ac.in

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1. Disposal of synthetic fibers is creating environmental issues; still, the recycling process of the synthetic fiber composites is not developed correctly.
2. The structures made by the synthetic fibers are sometimes having over strength and it is not required to maintain that much strength; this problem mainly occurs when the carbon fiber composites are used.
3. Using synthetic fibers in the construction increases the material cost.

Therefore, an alternative material to be identified to overcome the effects of synthetic fibers. For the past few decades, researchers are working on composites that are available naturally (Lau et al. 2018). Natural fibers like hemp, flax and jute have gained the researcher's interest by due to their specific properties like recyclability, renewability, low energy production and short growth cycle time (Bambach 2020). The main advantage of using natural fibers is that the composites are lighter in weight and bio-degradable. The cost of manufacturing composites is also significantly cheaper compared to advanced synthetic fibers. By considering the various advantages of natural fibers, a lot of research work is carried out in the past. Most of the natural fibers are environmentally friendly but not all the fibers.The best natural composite is made with the fiber which is available from the short renewable sources of the plant and easily biodegradable under the suitable conditions (Dittenber and Ganagarao 2012). Natural fibers are preferable to replace the E-glass fibers when the load applied to the member is medium or low. These fibers are reinforced with the matrix in different forms like woven, typically short and random orientation. Among all these orientations, the natural fibers which are placed in the woven form influence the mechanical and dynamic properties of the composite (Ramana and Ramprasad 2017).

Natural fibers are hybridized by another natural type of fiber or with synthetic fiber. This type of hybridization enhances the mechanical properties of the composites. Hybridized composites are mainly used for the structural and infrastructural point of view based on their load carrying capacity, energy absorption properties, housing panels and stability (Safri et al. 2018). People are getting more interest in the applications of natural fiber composites in structural and infrastructural elements where lower cost, environmentally friendly and moderate strength are required. The hybridized natural fiber composites develop load-bearing features like beams, roof, housing panels, pedestrian bridges, and water tanks in structural and infrastructural applications. Natural fibers are also used in non-loading members like wall cladding, insulation panels, and architectural elements. Natural fiber composites are also used for ballistic applications to safeguard humans against the impact and shock loads (Ticoalu et al. 2010).

1.1 Types of Natural Fibers

Nowadays, researchers are mainly focused on the natural fibers due to an environmental point of view and the increasing cost of synthetic fibers (Khan et al. 2018).

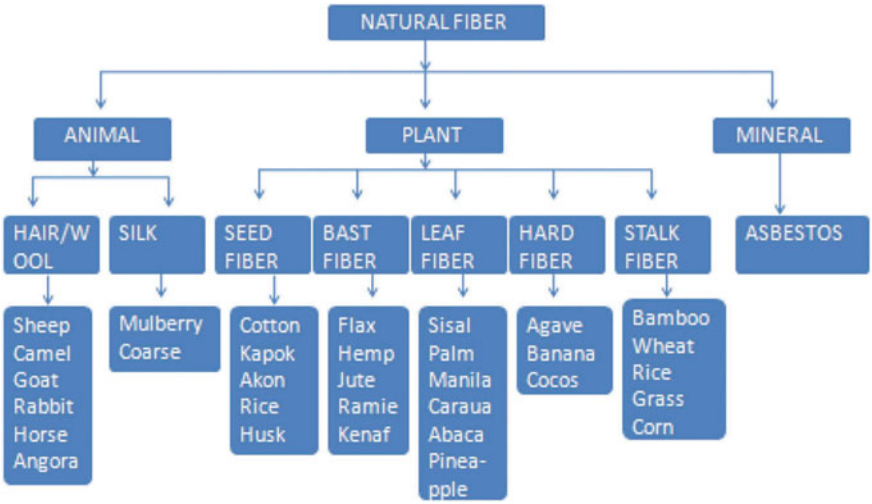


Fig. 1 Sources of natural fibers (Kumar et al. 2019)

Natural fibers are generally available naturally, and the sources of the natural fibers are mainly two categories, i.e., plant-based fibers and animal-based fibers. Plant-based fibers are derived from the plant's different parts like bast, leaves, fruits, and stalks. As same, the animal-based fibers are also derived from the body parts of the animal like fur, shell, bone, etc. (Nayak et al. 2020). Natural fibers are generally harvested once a year and few crops like hemp, jute and kenaf can be produced two times for a year. Natural fibers are having a high rate of assimilation of CO_2 and reducing the carbon content from the atmosphere. Figure 1 shows the different types of natural fibers based on the source of plant and animal, and Fig. 2 shows the life cycle of the natural fiber composites (Kumar et al. 2019).

1.2 Chemical Composition of Fibers

Cellulose is the major component in the natural fibers that develop the stability and strength of the cell as well as fiber. The amount of percentage of cellulose in the fibers influences the mechanical properties, economics of fiber production and usage of fibers in various types of applications. Cellulose contents in the fiber are used to identify the potential application of that fiber. If the fiber's cellulose content is very high, it is used for textiles and if the hemicellulose content is very low, then it will be used for making the ethanol.

Hemicellulose is slightly crosslinked when compared to cellulose and it is the combination of multi-polysaccharide polymers with the degree of polymerization and orientation is less than the cellulose. Generally, the filler part between the cellulose and lignin is hemicellulose, consisting of mannose, glucose and galactose. Lignin

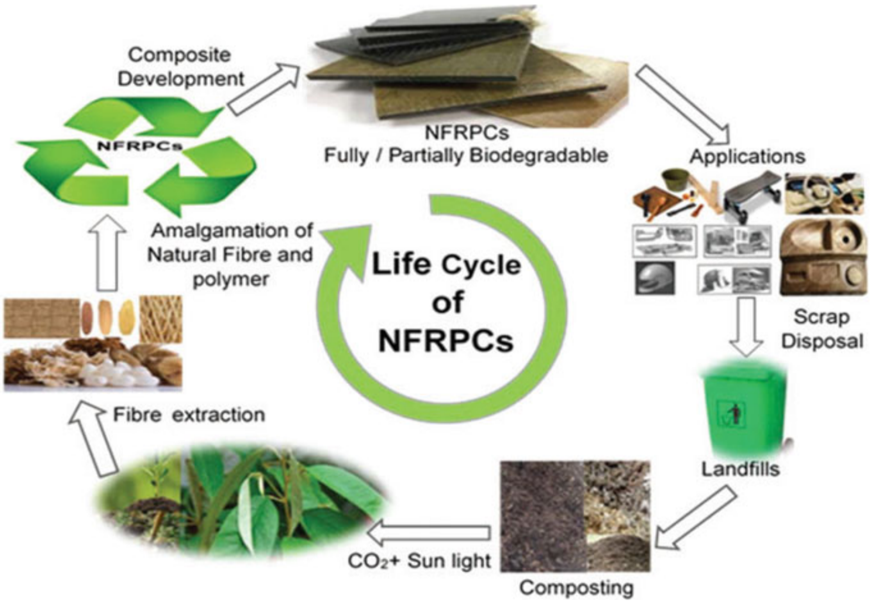


Fig. 2 Life cycle of Natural Fiber Reinforced Composites (NFRP) composites (Khan et al. 2018)

is a highly crosslinked molecular complex and acts like glue between fibrils, which form the cell wall.

Lignin provides the strength and stiffness of the cell wall and it protects carbohydrates from physical and chemical attacks. Natural fibers, which are having a high content of lignin, appears like finer and flexible (Reddy and Yang 2005). The strength of the fibers also depends upon the microfibrillar angle and aspect ratio. The higher strength of the fiber achievable when the microfibrillar angle of the fiber is low. Addition of lignin to the composites beneficial to the fibers up to a specific limit. Kraft lignin is added to the natural hemp fiber and it increases the impact, flexural and tensile strength of the composite. Simultaneously, if the added amount of lignin is excessive, it shows adverse effects on the composite (Wood et al. 2011). Cellulose, hemicellulose and lignin amount values vary from plant to plant and fiber type. Table 1 represents the chemical properties of the different kinds of natural fibers (Khan et al. 2018).

1.3 Mechanical Properties of Natural Fibers

Generally, the type of fiber is based on its source: animal, plant, or mineral. Cellulose is the main constituent of the fibers and protein is the main constituent in animal fibers. Due to the higher strength and stiffness, the plant fibers are used over the animal fibers.

Table 1 Chemical properties of natural fibers (Khan et al., 2018)

Fiber type	Chemical composition percentage (%)					
	Cellulose	Hemicellulose	Lignin	Pectin	Waxes	moisture
Flax	64.1	16.7	2	1.8	1.5	10
Hemp	55–80.2	12–22.4	2.6–13	0.9–3	0.2	6.5
Jute	64.4	12	0.2	11.8	0.5	10
Remie	68.9	13.1	0.6	1.9	0.3	10
Kenaf	37–49	18–24	15–21	8.9	0.5	–
Sisal	65	12	9.9	0.8	0.3	10
Cabuya	68–77	4–8	13	–	2	–
Abacca	56–63	15–17	7–10	–	3	–
Coir	19.9–36.7	11.9–15.4	32.7–53.3	4.7–7.0	–	0.2–0.5
Banana	48–60	10.2–15.9	14.4–21.6	2.1–4.1	3–5	2–3
Betelnut	35–64.8	29–33.1	13–26	9.2–15.4	0.5–0.7	–
Rice	28–48	23–28	14	–	20	–
Wheat	29–51	26–32	16–21	–	7	–
Oat	31–48	27–38	16–19	–	7.5	–
Sea grass	57	38	5	10	–	–
Bagasse	28.3–55	20–36.3	21.2–24	–	0.9	–
Bamboo	48.2–73.8	12.5–73.3	10.2–21.4	0.37	–	11.7

The top performance is mainly secured with the high cellulose percentage and the alignment of microfibrils in fiber direction, which is occurring in bast fibers(flax, hemp, jute, and kenaf). While comparing the plant fibers with the synthetic fibers, they have lesser strength. Still, the specific modulus and elongation at break have signified the importance of natural fibers to replace the synthetic fibers.

By considering the mechanical properties of different types of bast fibers, jute, flax, and hemp fibers will give better results compared to other natural products (Kabir et al. 2012) (Table 2).

1.4 *Chemical Treatment of Natural Fibers*

The main drawback of the natural fibers composite is that the combination of the hydrophilic nature of the fiber and hydrophobic nature of the matrix. Due to these different phases of the mixture, a weakening bond may be developed at the surface. To improve the significance of the fiber's interfacial bonding, surface is to be treated with different chemicals. By conducting the chemical treatment on the fiber, the hydrophilic nature would reduce and increasing the compatibility with the matrix.

Table 2 Mechanical properties of natural fibers (Khan et al. 2018)

Fiber type	Physical and mechanical properties of natural fibers and natural fibers						
	Density (g/cm^3)	Tensile strength (MPa)	Specific strength (MPa)	Youngs modulus (GPa)	Specific modulus (GPa)	Elongation (%)	Specific gravity
Flax	1.40	340–1600	535–1000	25–81	16.7–54	1.1–3.3	1.5
Hemp	1.48	550–900	372–608	70	–	0.8–3	1.5
Remie	1.50	200–1000	147–625	41–130	27–81	1.5–4	4
Kenaf	1.20	223–1191	641	11–60	10–42.9	1.6–4.3	1.3
Jute	1.46	385–850	269–548	9–31	6.9–20.7	1.4–2.1	1.3–1.5
Sisal	1.33	400–700	366–441	8.5–40	6.5–30.8	1.9–15	1.3
Abacca	1.80	980	–	–	–	–	–
Coir	1.25	170–230	146	3–7	2.5–5	14–30	1.2–1.4
Banana	1.35	711–789	444	4–32.7	3.6–27.3	2.4–3.5	1.1–1.2
Betelnut	0.2–0.4	120–166	–	1.3–2.6	1.0–1.9	22–24	1.3–1.4
Wheat	1.45	–	–	–	–	–	–
Elephant grass	0.817	185	–	7.4	–	3	–
Bamboo	1.10	500–575	454	27–40	50–67.9	1.9–3.2	0.4–0.8
Bagasse	1.50	170–350	–	5.1–6.2	3.6–4.1	6.3–7.9	1.4–1.5

Chemical treatment also improves the mechanical properties of the composites significantly.

Commonly used chemical treatments are alkaline, silane, acetylation, permanganate, isocyanate, and benzoylation. Out of these chemical treatments, alkaline treatment is the best chemical treatment for the natural fibers due to its inherent advantages. The alkaline concentration changes the densely packed crystalline to the amorphous phase in the fiber, and this phase will allow the penetration of chemicals (Ghelli and Minak 2011). The alkaline will reduce the amount of wax, oils, and lignin, which covered the outer part of the fiber cell wall. Fibers are immersed in NaOH for a certain time to influence the composition of natural fibers and increase the fiber's mechanical properties. For a flax-epoxy composite, the tensile properties have increased up to 30% by conducting alkaline treatment. In the case of sisal-polyester composite, treatment with 4%NaOH has given maximum tensile strength properties. As in the case of hemp fiber, 8% NaOH increased thermal stability. In the case of jute-vinyl ester the fiber treated with the 5%NaOH has increased the flexural strength by 20% and tensile strength by 19% (Reddy and Yang 2005). At the same time, the excess usage of alkaline will lead to the damage of the fiber (Ismail et al. 2019).

2 Applications of NFRP Composites in Structural Member

At present, the researchers are showing more attention towards natural fiber-reinforced composites' applications in a structural and infrastructural applications where the materials need to be lower in weight and moderate strength is required. Natural fibers composites are used in automotive body parts, wind blades, and non-structural elements from the past decades. While considering the structural and infrastructure market, the natural fibers are used in making load-carrying members such as beams, water tanks, columns, bridge decks for pedestrians and panels for multi-purpose (Lau et al. 2018).

2.1 Mechanical Properties of the Different Types of Synthetic/Natural Hybrid Composites

Hybrid composite is generally a combination of two or more fillers into a matrix. Fillers are mainly characterized based on their origin, i.e., either natural or synthetic fibers. Natural fibers have some specific advantages compared to synthetic fibers in the aspects of low weight, renewable and sustainability. Synthetic fibers will give better strength when compared to natural fibers. Many researchers have found that natural fibers are hydrophilic and synthetic fibers are hydrophobic. Both the type of fibers are having certain limitations when compared to each other. Researchers identified that to increase the performance of the composite, the hybridization of natural fibers and synthetic fibers is needed. And the mechanical properties of these hybrid composites are mainly based upon the selection of matrix, surface modifications, the orientation of the fiber and interfacial adhesion of different types of lamina (Mochane et al. 2019).

2.2 Performance of Synthetic-Natural Fibers Hybrid Composites

To enhance the performance of the resultant composite, the hybridization of synthetic and natural fibers is required. Generally, natural type of fibers are attracted towards moisture and it will affect the composite performance. To reduce the moisture absorption, surface modification was required by the chemical treatment. These chemicals sometimes harsh in nature and damage the fiber properties. When the hybridization takes place between the synthetic and natural fibers, then it will reduce the moisture absorption, maintain the balance between the cost of the materials and it gives a chance to change the surface modification chemical. The fiber fraction will influence the performance of the composite. The addition of carbon content increases the tensile properties of the composite and strength of the composite.

Akil et al. (2014) have investigated the synthetic-natural hybrid composite's performance by considering the glass fiber as synthetic and jute fiber as a natural type of fiber. These fibers are added to the polyester resin to manufacture the composite. The fibers are having the uni-directional. The composites are manufactured by considering a high fiber to matrix ratio of 70:30 and from the volume point of view, the ratio was considered as 50:50. Tests are conducted on four types of laminates by changing the lamina's fiber orientation and stacking sequence. They have conducted the moisture absorption test and the tensile test to determine the properties of the composite. Based on the results, Akil et al. (2014) identified that the hybrid composite has superior mechanical properties over the nonhybrid composite made with jute fibers only. The hybridization also reduced the moisture absorption of the composite. This type of hybridization makes the composite perform better and balances the cost of the materials.

Ramana et al. (2017) investigated on the jute-carbon hybrid epoxy composites. To reinforce the fibers, the thermosetting resin epoxy has been used. Four plates have been manufactured by fixing the epoxy percentage as 55% and changing the carbon and jute laminas. These composites include plain jute composite, plain carbon composite and jute carbon composite. By conducting the tests the tensile strength, flexural strength, and impact strength have been examined. Based on the results, the tensile strength of jute/carbon composite is almost equal to the carbon epoxy and is more than the jute epoxy composite. While considering the impact strength, the jute/carbon hybrid performs similar to the jute-epoxy composite and much more than the carbon-epoxy composite. The flexural strength of the composite made with jute/carbon has served better than the othercomposites.

Kureemun et al. (2018) have conducted the tests on carbon- flax hybrid composite. These fibers combined with the thermosetting resin, i.e. epoxy for fabricating the composites. By considering the different volume fractions of the carbon and flax, the laminates are made. For every laminate, they have considered four laminas by changing the fiber orientation and stacking sequence. The fiber volume fractions of plain carbon epoxy and plain flax epoxy are 66 and 29%. From the results with the 8% of carbon by volume the strength and stiffness are increased more than 50 and 30% increse in specific strength compared to aluminum. Overall the hybrid composite has increased the mechanical properties over the non-hybrid flax composite.

2.3 Performance of Natural-Natural Fibers Hybrid Composites:

The hybrid composites can be manufactured with even natural-natural type of fibers. The composites made with different natural fibers have exhibited significant advantages in various fields like automotive parts, agricultural, biomedical, residential, and building applications. These types of hybrid composites have reduced the cost of the materials, and the resultant composite weight is also reduced (Mochane et al. 2019).

The composite has been manufactured by considering the jute, kenaf fiber and hemp fiber. The epoxy resin is used to reinforce the fibers. The composites are fabricated by the woven type of mats. By changing the stacking sequence different type of composites has been produced. To identify the mechanical properties, various tests have been conducted, such as tensile test, flexural test, and water absorption test. Based on results, it was observed that the hybridization of the natural fibers reduced the water absorption capacity of the fibers. If the fibers are immersed longer, then it will effect the strength of the composite. Sometimes, the fibers' delamination and cracking in the matrix also increase the water absorption capacity and influence the composite's strength parameters. The hybridization between the different types of natural fibers has increased the tensile strength and flexural strength of the composite due to the load sharing between the different types of fibers (Maslinda et al. 2017).

The composite has been made by considering the fibers of sisal, jute and curaua fiber. The epoxy resin is used to reinforce the fibers. The fiber fraction is 30 and 70% of epoxy are considered for manufacturing the composite. The fibers are treated by the process of alkalization to increase the mechanical properties of the composite. The hybridization process produced the better results of the composites. The improvement in tensile strength of the jute/sisal, jute/curua and jute/glass over the untreated pure jute composite is 68%, 77% and 90%, respectively. The flexural strength has increased in all the composites except jute/sisal composite due to the chemical treatment. Even the impact strength of all the composites has increased due to the chemical treatment except in the case of jute/curua hybrid composite. Based on the results, it has been observed that the usage of sisal and curua fibers will replace the glass fibers in composites. These types of natural hybrid composites can be used for the low load-bearing structures (Cavalcanti et al. 2019).

2.4 Impact Characteristics of Natural Fiber Composites

Most of the engineering structures are often exposed to impact load by the foreign objects in the maintenance of the composite, repairing, manufacturing, and service conditions. When compared to the metallic structures, the laminated composites are more vulnerable to damage created by impact loading. In manufacturing or repairing the composite, sometimes the tools may fall on composite and make impact load on that. In aircraft landing, the impact load is added on the cover material by the debris projectile from the runway due to high velocity contact between runway and tires. Impact loading is generally in two forms like low velocity and high velocity. Due to the low velocity of the impact, the fibers face matrix cracking failures, internal damage, and fibers delamination. The resistance of the impact loading mainly depends on the fiber's stacking sequence and type of fiber. To examine the impact resistance of fiber, the low velocity and high velocity tests are used. In low-velocity test, the impactor is released between 5 and 15 m/s while in the high-velocity impact test the impact is 2500 m/s. The low-velocity tests damage the composite by applying the load still the composite is able to function.While in case of a high-velocity test, the composite is completely damaged due to the penetration of the impactor. The composite manufactured by the glass-carbon fiber has performed better than the metallic bumper, which is also reduced by 33% in the weight point of view. Further research has been extended to hybrid composites by replacing the synthetic fibers with the natural type of fibers. The hybridization of natural-synthetic fibers will reduce the weight of the composite (Safri et al. 2018).

Generally, for structural design, the strength of roof and impact strength are the important aspects. The coir fiber-based composites are used for automotive applications because of their higher impact strength and it is the beneficial to the automotive industry. Usually, the coir composites are low in tensile strength, but the composite's impact strength is comparatively better than other composites. The cotton fiber composites reinforced in epoxy resin also exhibit better results in past research (Ticoalu et al. 2010).

Natural-Natural type of hybridization of the composites also improves the impact strength of the composite. The impact strength of the pure epoxy is 4 kJ/m^2. The hybridization of the composite manufactured by the Jute/Hemp/Flax/Epoxy has the maximum impact strength of 10.19 kJ/m^2. While in the case of Jute/Epoxy and Jute/Hemp/Epoxy has a full impact strength of 7.68 kJ/m^2 and 6.93 kJ/m^2, respectively. These variations are developed due to the interfacial bonding between the types of natural fibers added with epoxy resin (Chaudary et al. 2018).

The hybridization of synthetic-natural fibers alters the impact strength of the composite. A Charpy test has been conducted on the flax fiber composite and the result value is only 38.4 kJ/m^2. Whereas if we consider the carbon composite, then the composite impact strength is 820% greater than the flax fiber composite. The hybridization of the flax and carbon fiber composite has improved the impact strength of about 400% over the flax fiber composite. This much of strength to the composite is incorporated by adding 12% of carbon fiber (Flynn et al. 2016).

In the process of hybridization among the different types of fibers, the stacking sequence also affects the composite's impact strength. The composite prepared by the alternative layers of synthetic and natural fibers will have greater impact strength (Arpita et al. 2017).

2.5 Advanced Composite Beams and Columns

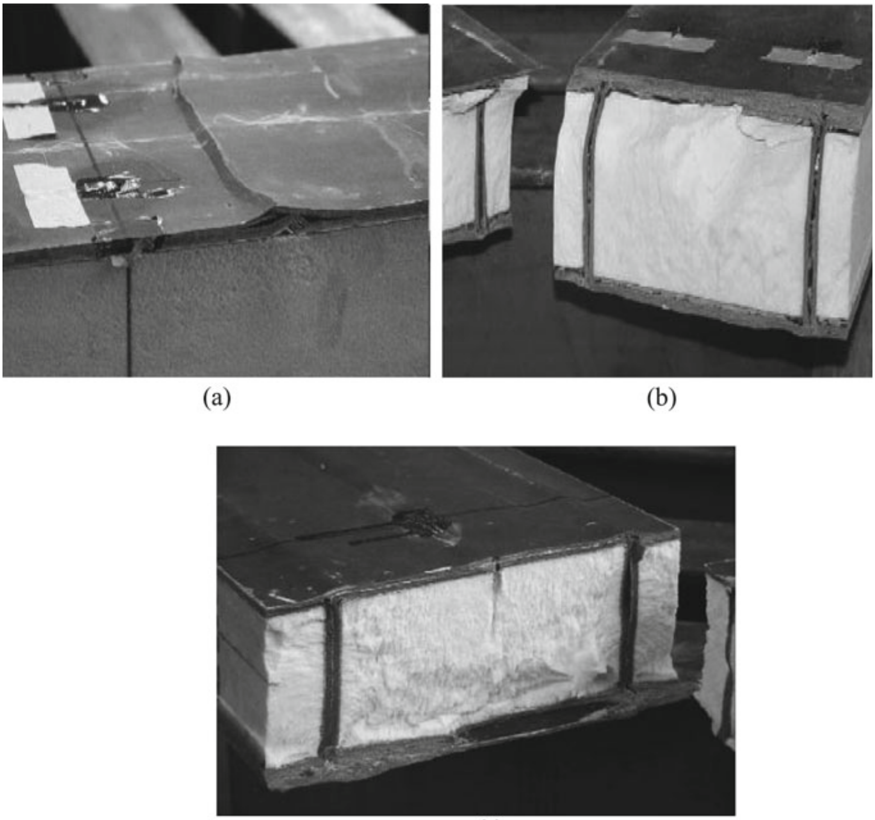
The steel used in the beams and columns is viable to attract the moisture, leading to the steel's corrosion. Then the deterioration of the member will take place due to the corrosion of the steel. And considering the density point of view, the members constructed by using the steel and concrete leads to an increase in the member's weight. The advanced composite material is one of the best options to replace the steel plates or steel jackets that are used in construction. For a long span of a building, the composite columns and beams are suitable. Figure 3 shows the different types of composites beams and columns (Fan and Fu 2017).

Fig. 3 Natural fiber composites for beams and columns in construction (Fan and Fu 2017)

The beam is the primary component in any type of building, bridge or any engineered structure. The structural member which is in the mode of bending or in the mode of flexural then that member is treated as a beam. Based upon the design requirements, the shape of the beam is either in rectangular or square mostly. The flexural strain parameters, stress, modulus of elasticity, and deflection of the beams have been found out by using the three-point or four-point bending tests (Ticoalu et al. 2010).

Using the natural fibers to manufacture the beams, a composite sandwich is mainly used among the other types. By incorporation of different types of layers, the composite beam is fabricated. The core material is sandwiched between the same type of material at top and bottom, which have more strength than the inner material. Dweib et al. (2004) investigated the sandwich beam made with cellulose fibers and reinforced with the acrylate epoxidized soy-bean oil incorporated by foam care. Vacuum Assisted Resin Transfer Molding (VARTM) method is used to manufacture the beams. Flax beams are cast by wrapping the foam core with sufficient reinforcement material. The beams are casted by various fiber combinations like flax mats, woven glass fiber, recycled paper with chicken feather mats, recycled paper with corrugated paper and recycled paper with woven glass fiber. Four-point bending test is conducted on the beams to evaluate the mode of failure, strength and stiffness. From the failure loads, it has been observed that the E- glass beam is having the ultimate load of 39kN and flax beam is having the lowest ultimate load of 10kN. The ultimate loads of recycled paper with chicken feathers and corrugated is almost equal, and the values are 24.2 kN and 25.8 kN respectively. Figure 4 shows the different fracture surfaces of the recycled paper beam. Normally wood members are generally used as beams in buildings from the past. The strength of the wood beams mostly will fall within the range of 9 kN to 26 Kn,whereas the recycled paper beam with chicken feathers and corrugated cardboard has more strength than wood beams.

Sandwich composites are lightweight composites and having applications in marine fields, aerospace, wind energy and civil engineering structures. These composites are manufactured by two stiff thin skins sandwiched by the thick lightweight core material. Waddar et al. (2019) conducted the sandwich beam composite's buckling and free behavior under the axial compressive loads. Sisal



(a) (b)

(c)

Fig. 4 Fracture surfaces of the recycled paper beams **a** recycled paper with chicken feathers. **b** Recycled paper with corrugated paper. **c** Recycled paper with woven E-glass fiber (Dweib et al. 2004)

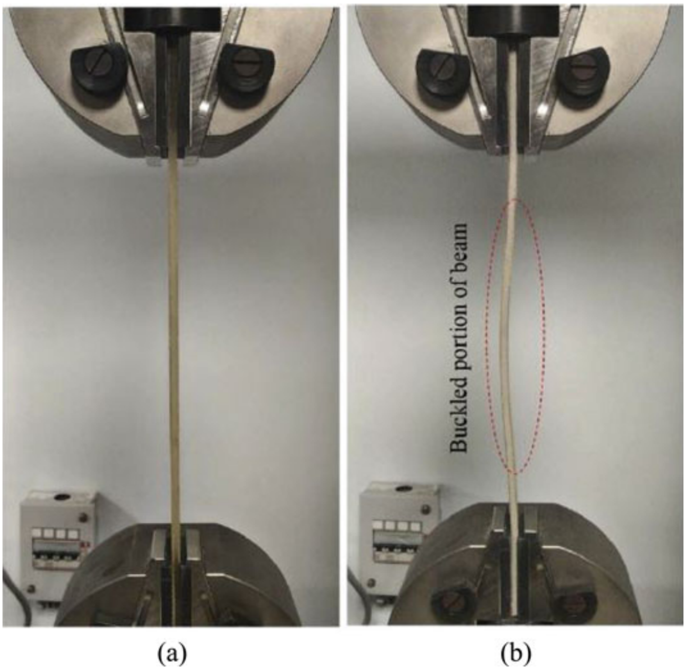


Fig. 5 Syntactic foam sandwich beams **a** before buckling, **b** after buckling (Waddar et al. 2019)

is considered the syntactic foam which fills the top and bottom skin of the sandwich and core part of the sandwich is filled through the epoxy resin.To increase the stiffness of the foam, the cenospheres is used and the treated cenospheres is used to improve the modulus and stiffness of the foam. After demolding of composite, the resultant thickness of the manufactured sandwich is 4 mm. The beams are tested against the axial compressive load using the universal testing machine. The beams exhibited the global buckling modal shape without skin wrinkling and skin delamination. And due to the increase of the filler in the core, the buckling and natural frequencies are also raised. During the buckling test the prepared sandwich composites show the global buckling mode and maximum displacement at the middle of the composite, as shown in Fig. 5. The buckling load is increased in the untreated and treated composites compared to neat epoxy composites in the range of 7.85–25.44% and 19.92–38.98% (Waddar et al. 2019).

2.6 Ballistic Applications

Day by day, conflicts are rising worldwide and safeguarding the man's power of a particular country is a critical issue. The humans should be safeguarded against the shock and impact loads by the well-developed protection system known as personal protective armor. Generally, a multilayered ballistic armor system(MBAS) is used as a protection system which includes a ceramic front plate, flexible composite laminate, lightweight and ductile material as shown in Fig. 6 due to various stages of its layers MBAS protects the user from ballistic loads. The ballistic load is an impact caused by low mass projectile with high velocity triggered by some propelling force. These types of impact loads can also lead to fatal conditions to humans (Nayak et al. 2020). Composite laminate which is used in MBAS is synthetic fiber-reinforced composite laminate mostly. MBAS should be light in weight because it provides mobility to the user. To make the composite lighter in weight, various alternative materials have been identified, and natural fibers are alternative materials to synthetic fibers (Medvedovski 2010).

Tirillo et al. (2017) investigated the response of the basalt/ carbon fiber reinforced with epoxy resin subjected to high-velocity impact. The different stacking sequences of the fiber mats sandwich-type composite and intercalated type composite have been manufactured. To evaluate the difference between the carbon and basalt, the plain type of carbon/epoxy and basalt/ epoxy composites were also fabricated. For all the composites, the plate's thickness is 4 mm, and fiber volume fraction is considered in the range of 58–64%. With the speed of 165–475 m/s, a spherical tempered steel projectile was considered to conduct the impact test.

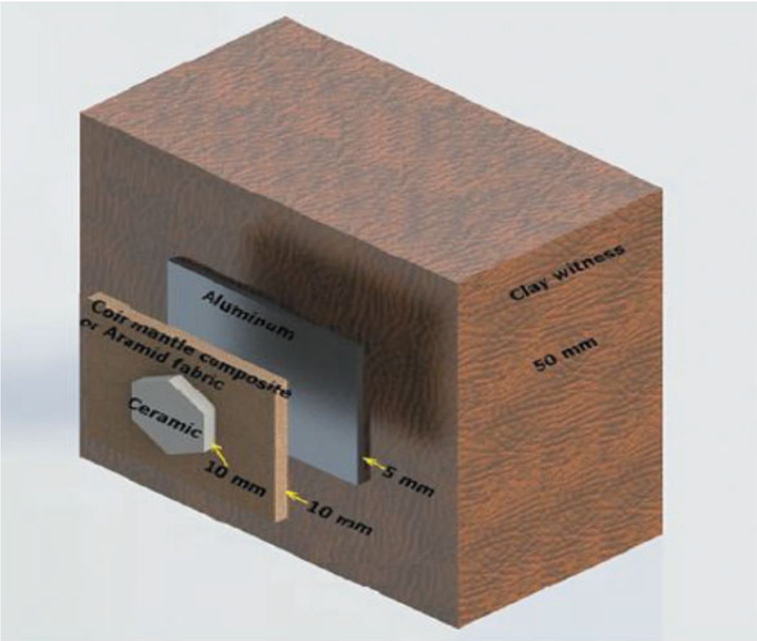


Fig. 6 Typical MBAS model for testing (Medvedovski 2019)

The results show that the hybrid type of composites have performed better than all the configurations of carbon/epoxy composites when the ballistic load is applied. Hybrid composites are failed because of the fibers' debonding and in the case of the carbon/epoxy composites, the failure in the form of fiber splitting and brittleness of the fiber. Intercalated composites are manufactured with the less basalt fiber content even though it exhibits better performance over the sandwiched type due to the different stacking sequence of the fibers.

Architecture

Up to nineteenth century almost all the buildings are modeled with natural fibers that are extracted from the bamboo. Most builders use the vernacular architecture these days by considering steel, concrete, glass, carbon, and bricks. When the non-vernacular architecture occurs in buildings and energy consumption is about 40% CO_2 emissions and 15% of it is needed to produce the materials required. By considering the natural fibers to replace non-renewable materials, the construction cost of buildings will be cheaper.

In most developing countries, the walls' internal and external panels are constructed by the use of natural fibers. The hemp fibers are mixed with concrete to casting the side walling of the buildings in England, as shown in Fig. 7. The main advantages of using natural fibers in vernacular architecture are wall cladding in the deck and outdoor furniture construction. The main aspect of architecture is the used materials should be easily convertible to the required shape. By using the natural type of fibers the resultant composites can be converted easily into any required shape (Steffens et al. 2017).

2.7 *Retrofitting of RCC Structures*

The reinforced concrete structures sometimes not be durable for a long time due to the members' deterioration. This deterioration is taking place due to inappropriate reinforcement, fatigue failure and corrosion under aggressive weather conditions (Padanattil et al. 2017).To overcome this condition, the deteriorated members should be retrofitted with some other external material. The wrapping of hybrid sisal glass fiber reinforced composite polymer (HSGFRP) around the concrete cylinder has greatly influenced the specimen's results. Three types of models are considered for testing the strength properties of the cylinder. In the first model, one layer of HSGFRP wrapped around the cylinder, in second model two layers of HSGFRP is placed, and in the third model three layers of HSGFRP is wrapped around the cylinder as shown in Fig. 8

The energy absorbed in the plain concrete specimen when tested against the load is 64.86 Nm whereas in the case of one layer wrapped cylinder it is 1032.25 Nm; in two layers wrapped cylinder it is 1415.64 Nm, and in the case of three layers wrapped cylinder it is 1886.25 Nm. The axial strain has improved by almost 44% in the case of HSGFRP. This improvement of axial strain also improves the ductility of

Fig. 7 Hemp line concrete walling(Steffens et al. 2017)

(a) plain concrete cylinder (b) cylinder wrapped with HSGFRP

Fig. 8 Retrofitting the cylinder specimens (Padanattil et al. 2017) the member. The wrapping of HSGFRP is also increasing the seismic resistance of the reinforced members. To enhance composites' results, the fibers are required to be treated chemically with the process of alkalization (Padanattil et al., 2017).

2.8 Acoustic Applications

Berradi and Lannace (2015) identified that in recent years, natural fibers became the alternative for synthetic fibers to use in the sound-absorbing panels. Natural fibers have good thermal insulation properties, and these fibers are not harmful for health while manufacturing. The materials' high porosity content is required to absorb the sound and pass it to the matrix to the dissipation of sound. Authors considered different types of fibers like kenaf, jute, wood, cane, cork, sheep wool, and cardboard to prepare the composites and tested against the sound absorption capacity and flow resistance.

Among all the composites, sheep wool and coconut have higher values and are recognized as promising materials for absorbing the sound. The noise reduction coefficient is maximum for sheep wool of about 0.7 and a minimum for wood mineralized of 0.20. All-natural fibers are good while absorbing the medium or high frequencies of sound. But whereas in the low frequencies, the absorbing capacity is low, this drawback can be balanced by using the fiber's thickness and incorporating the air gaps in the composite.

2.9 Fire Resistance of Natural Fiber Composites

Natural fibers are considered to replace the synthetic type of fibers for use in the structural members. Flammability is one of the main limits of applications of natural fibers. Generally, bio fibers are flammable. Thus the heat released from the natural fibers is much more than the synthetic fibers (Chapple and Anandjiwala, 2010). The strength and stiffness of the fiber-reinforced polymers can be reduced at high range of temperatures. The glass fibers have a high thermal capacitance and if the fire once has started on the glass fiber due to its stored thermal energy, the reignition also occurs on the surface of the fiber. These fires will get ignited at one and it leads to difficulty to the firefighters.

In case of natural fibers, the fiber's performance is based on the chemical composition of the fiber. Natural fibers with the cellulose content in high ranges are highly flammable, and the fibers having the hemicellulose content are lesser flammable. The formation of char is better with more lignin content. If the fibers have the silica/ash, they also perform better against the fire. Apart from the fiber's chemical composition, the microstructure that represents the lower polymerization and higher crystallinity improve the fire performance (Dittenber and Ganagarao 2012).

Based on the thermogravimetric analysis, the thermal degradation of the fibers can be evaluated. Plant fibers like sisal and jute have an equal value of thermal degradation of 340 °C and the flax fiber has the value of 345 °C. Cellulose decompositions is occurred between 260 and 350 °C and in the process of decomposition, it will release tars, noncombustible gases and some char. As in the case of hemicellulose, the fiber decomposition falls in the range of 200 and 260 °C and releases more combustible gases and less tar when compared to cellulose.

Composite flammability mainly depends upon the type of matrix, and along with that, it also depends upon the type of fiber and the bonding between the fiber and matrix. Sometimes, the core materials present in the composite also affect the composite's fire properties. The composite fire resistance can be improved by adding a fire retardant or a thermal barrier coating. These additions can easily be added to the thermoset resins, but thermoplastic resins still need to be done (Burgueno et al. 2005).

3 Concluding Remarks

Natural fibers used in composites as a reinforcing material have been explored throughout the world due to its inherent advantages and many applications. Most of the natural fibers are produced from agricultural waste and it adds some contribution to the national GDP of agro-based economics. The remarks from the present investigation are summarized as follows:

- Natural fibers are becoming promising materials to replace the E-glass fibers for secondary level structural members.
- The moisture absorption capacity of the natural fibers can be reduced by the treatment of the fibers with different types of chemicals and among all those alkalinizations has resulted better properties.
- Flax fibers have a superior energy absorption capacity. Due to this, flax fibers have better performance over the jute and hemp fibers in case of ballistic loads.
- Composites are added with the flame retarders to improve the flammability and thermal stability.
- Compared to glass fiber, the natural fiber-reinforced composites have comparable structural properties in the view of strength and stiffness.
- NFRPCs produce better mechanical properties when the fiber weight fraction is around 30–40%.
- With the 5 wt% alkali treatment, the NFRPs will achieve better tensile and flexural properties.
- The addition of lignin content to the natural fibers also improves the impact properties of the composite.
- Hybridization of natural-synthetic fiber is influencing the composite properties in a greater way. With 8% of carbon by volume in the composite, about 50% more strength and stiffness are achievable.

- The addition of filler or nanofiller also reduces the few limitations of the composite. By using the flame retarders, the flammability and thermal stability of the composite is increased.
- The composites' strength and modulus will reduce if the composites are immersed in water for a longer duration.
- Significant research has been carried out to investigate biopolymers, fire retarders, and chemical treatment of the fibers.

4 Research Gaps and Future Research Needs

Even though many of the factors affect the usage of natural fibers in structural load members still, those fibers are attracted by many researchers by their renewability, biodegradability, and cost competitiveness (Lau et al. 2018). Further, to improve the properties of natural fiber composites, a lot of research is required in the future according to the following aspects:

- In the previous studies, thermosetting resins and thermoplastic resins are added to the natural fibers to manufacture the composites. The addition of these types of resins made composites partially biodegradable. To manufacture composites as fully biodegradable, further research needs to be carried using biodegradable resins for manufacturing the natural fiber composites.
- The main drawback of the natural fibers is that they have a hydrophilic nature, absorbing more moisture. Many of the researchers have identified different chemical treatments to reduce the hydrophilic nature of the fiber. Much research has determined that alkanization is the effective chemical treatment compared to all, but surplus amounts of alkaline will damage fiber texture. Further research is needed to identify alternative chemical treatments by considering different chemicals to improve natural fiber properties.
- Many of the researchers have investigated the properties of natural fiber composites in normal temperature conditions only. But if the natural fiber composites are using in industries and ballistic applications, they are subjected to elevated temperatures. Further research has to be investigated inflammability property to identify the different fire retarders and methods to improve natural fibers fire resistance at high temperatures.
- The past research has concluded that natural fiber composites mechanical properties are low compared to synthetic fibers. To enhance natural fiber composites properties competitively, hybridization is needed among the natural fibers and synthetic fibers to manufacture the composites. Hence, further research has been needed to identify the hybridization methodology while incorporating the natural fibers into synthetic fibers.
- Previous studies have shown that bast fibers like flax, hemp, and jute have better ballistic resistance than other natural fibers. Further research must be needed by considering the fibers from the stalk, seed, and hard fiber in ballistic applications.

- In the previous studies, a lot of research has been done by considering the natural fibers to make the composites. Nowadays, composites filled with natural fillers like cellulose nanocrystals, nano fibrillated cellulose are attracting researchers. These type of fillers improves the mechanical and thermal properties. Further research has to be carried out by identifying different kinds of natural fillers and the methodology of adding filler material into the polymers.

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References

Akil HM, Santulli C, Sarasini F, Tirillo J, Valente T (2014) Environmental effects on the mechanical behaviour of pultruded jute/glass fibre-reinforced polyester hybrid composites. Compos Sci Technol 94:62–70

Arpita GR, Sanjay MR, Senthamaraikannam P, Barile C, Yogesha B (2017) Hybridization effect of sisal/glass/epoxy/filler based woven fabric reinforced composites. Express Technol 41:577–584

Bambach MR (2020) Direct comparison of the structural compression characteristics of natural and synthetic fiber-epoxy composites: flax, jute, hemp, glass and carbon fibers. Fibers 62:01–14

Berradi U, Lannace G (2015) Acoustic characterization of natural fibers for sound absorption applications. Build Environ 94:840–852

Burgueno R, Quagliata MJ, Mehta GM, Mohanty AK, Misra M, Drzal LT (2005) Sustainable cellular biocomposites from natural fibers and unsaturated polyester resin for housing panel applications. J Polymer Environ 13:139–149

Cavalcanti DKK, Banea MD, Neto JSS, Lima RAA, Da Silva LFM, Carbas RJC (2019) Mechanical characterization of intralaminar natural fibre-reinforced hybrid composites. Compos Part B: Eng 175:107149

Chapple S, Anandjiwala R (2010) Flammability of natural fiber-reinforced composites and strategies for fire retardancy: a review. J Thermoplast Compos Mater 23:871–893

Chaudary V, Bajpai PK, Maheswari S (2018) Studies on mechanical and morphological characterization of developed jute/hemp/flax reinforced hybrid composites for structural applications. J Nat Fibers 15:80–97

Dittenber DB, Ganagarao HVS (2012) Critical review of recent publications on use of natural composites in infrastructure. Compos A Appl Sci Manuf 43:1419–1429

Dweib MA, Hu B, Donnel A, Shenton HW, Wool RP (2004) All natural composite sandwich beams for structural applications, composite structures. Compos Struct 63:147–157

Fan M, Fu F (2017) Introduction: a perspective-natural fibre composites in construction. In: Advanced high strength natural fibre composites in construction, pp 1–20

Flynn J, Amiri A, Chad U (2016) Hybridized carbon and flax fiber composites for tailored performance. Mater Des 102:21–29

Ghelli D, Minak G (2011) Low velocity impact and compression after impact tests on thin carbon/epoxy laminates. Compos Part B: Eng 42:2067–2079

Ismail MF, Sultan MTH, Hamdan A, Shah AUM, Jawaid M (2019) Low velocity impact behaviour and post-impact characteristics of kenaf/glass hybrid composites with various weight ratios. J Mater Res Technol 8:2662–2673

Kabir MM, Wang H, Lau KT, Cardona F (2012) Chemical treatments on plant-based natural fibre reinforced polymer composites: an overview. Compos Part B: Eng 43:2883–2892

Khan MZR, Srivasthava SK, Gupta MK (2018) Tensile and flexural properties of natural fiber reinforced polymer composites: a review. J Reinf Plast Compos 37:1435–1455
Kumar R, Ul Haq MI, Raina A, Anand A (2019) Industrial applications of natural fibre-reinforced polymer composites–challenges and opportunities. Int J Sustain Eng 12:212–220
Kureemun U, Ravandi M, Tran LQN, Teo WS, Tay TE, Lee HP (2018) Effects of hybridization and hybrid fibre dispersion on the mechanical properties of woven flax-carbon epoxy at low carbon fibre volume fractions. Compos Part B: Eng 134:28–38
Lau K, Hung P, Zhu MH, Hui D (2018) Properties of natural fiber composites for structural engineering applications. Compos Part B: Eng 136:222–233
Maslinda AB, Abdul Majid MS, Rizuan MJM, Afendi M, Gibson AG (2017) Effect of water absorption on the mechanical properties of hybrid interwoven cellulosic-cellulosic fibre reinforced epoxy composites. Composites Struct 167:227–237
Medvedovski E (2010) Ballistic performance of armour ceramics: Influence of design and structure. Part 2. Ceram Int 36:2117–2127
Mochane MJ, Mokhena TC, Mokhothu TH, Mtibe A, Sadiku ER, Ray SS, Ibrahim ID, Daramola OO (2019) Recent progress on natural fiber hybrid composites for advanced applications: a review. Express Polymers Lett 13:159–198
Nayak SY, Sultan MTH, Shenoy SB, Kini CR, Samant R, Shah AUM, Amunthakkanan P (2020) Potential of natural fibers in composites for ballistic applications—a review. J Nat Fibers 1–11
Padanattil A, Karingamanna J, Mini KM (2017) Novel hybrid composites based on glass and sisal fiber for retrofitting of reinforced concrete structures. Constr Build Mater 133:146–173
Ramana MV, Ramprasad S (2017) Experimental investigation on jute/carbon fibre reinforced epoxy based hybrid composites. Mater Today: Proc 4:8654–8664
Reddy N, Yang Y (2005) Biofibers from agricultural byproducts for industrial applications. Trends Biotechnol 23:22–27
Safri SNA, Sultan MTH, Jawaid M, Jayakrishna K (2018) impact behaviour of hybrid composites for structural applications: a review. Compos Part B: Eng 133:112–121
Steffens F, Steffens H, Oliveira FR (2017) Applications of natural fibers on architecture. Procedia Eng 200:317–324
Ticoalu A, Aravinthan T, and Cardona F (2010) A review of current development in natural fiber composites for structural and infrastructure applications. In: Southern Region Engineering conference, pp 113–117
Tirillo J, Ferrante L, Sarasini F, Lampini L, Barbero E, Sanchez Saez S, Valente T, Gaudenzi P (2017) High velocity impact behaviour of hybrid basalt-carbon/epoxy composites. Composite Struct 168:305-312
Waddar S, Pitchamani J, Doddamani M, Barbero E (2019) Buckling and vibration beviour of syntatic foam core sandwich beam with natural fiber composite facings under axial compressive loads. Compos Part B:Eng 175:107133
Wood BM, Coles SR, Maggs S, Meredith J, Kirwan K (2011) Use of lignin as a compatibiliser in hemp/epoxy composites. Compos Sci Technol 71:1804–1810