Effects of Natural Weathering on Aesthetics, Thermal and Mechanical Properties of the Bio-composites

Tarkan Akderya, Cemal Bilir, and Buket Okutan Baba

Abstract Bio-composite materials, which are a serious alternative to synthetic-based fibre and matrix materials due to their high characteristics and biodegradability, cause difficulties and uncertainties for usage conditions due to their high sensitivity to climatic conditions. Scientific studies have shown that climatic factors such as temperature, humidity, radiation, UV rays, and acid rain that act synergistically in natural weathering conditions, cause degradation and changes in the bio-composite material's characteristics. Examining the material's behaviour under natural weathering conditions provides the most realistic and reliable results in terms of determining the shelf life of the material and knowing its behaviour in the usage environment. In this study, changes in thermal, mechanical, and aesthetic properties of bio-composite materials exposed to natural ventilation conditions were investigated. It has been observed that natural weathering induces dramatic decreases in thermal and mechanical properties of bio-composite materials, especially with the effect of prolonged exposure times, and causes changes in colour, surface deterioration and changes in shape.

Keywords Natural weathering · Bio-composite · Mechanical properties · Thermal properties · Aesthetics

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1 Introduction

Deterioration of the environment's natural equilibrium, increasing natural disasters, and environmental awareness on governmental and personal basis have led to increased sustainability awareness. Therefore, the search for environment-friendly products used in industrial and daily life has been launched. One of the areas where environment-friendly material applications are used is the field of composite material production. In this respect, it has begun to search for green composite materials that can be an alternative to synthetic fibre and synthetic matrix composite materials with a wide range of use and superior properties.

Within the scope of the search for sustainable materials, it is seen that the use of biobased plastics and their composites (bio-composites) is on a significant growth trend. Bio-composites produced from local and renewable sourced materials contribute to sustainability by increasing ecological efficiency, contributing to the establishment of green chemistry and green industry, and paving the way to produce new generation materials, processes and products (Bharath and Basavarajappa 2016). In reducing the carbon footprint caused by traditional composite materials, bio-composite materials can be an alternative, and these materials can also help reduce the strain on the environment (Chang et al. 2020).

Bio-composite materials can be evaluated in two main classes: green composites or partly eco-friendly composites, depending on the fibres and matrix's sustainability. While the matrix and fibres of green composites are entirely obtained from renewable resources, either the matrix or fibres of partly eco-friendly composites are obtained from environmentally friendly sustainable sources (Mohanty et al. 2005; Mitra 2014; Peças et al. 2018; Akderya et al. 2020).

Natural fibre-reinforced bio-composites are additives that are used as reinforcement elements, obtained from natural sources. When compared with synthetic fibres, they have superior characteristic properties such as renewability, abundance, biodegradability, affordability, flexibility during the production process, specific stiffness, low carbon footprint and low density (Nabi Saheb and Jog 1999; Akil et al. 2011; Mukherjee and Kao 2011; Faruk et al. 2012; and Hiremath 2020; Chaudhary et al. 2020). The classification of natural fibres is schematised in Fig. 1, and accordingly, natural fibres can be divided into two main classes, organic and non-organic. Organic natural fibres can be examined in two different groups, plant-based and animal-based. As an example of plant-based natural fibres as a reinforcement element; jute (Rahman et al. 2014), flax (Li et al. 2009), hemp (Popa et al. 2013), kenaf (Kamal et al. 2014), ramie (Krasowska et al. 2010), banana (Rodríguez et al. 2018), coir (Sanal 2016), kapok (Sellivam et al. 2016), bamboo (Astadini et al. 2020; del Pilar Fajardo Cabrera de Lima et al. 2020; Hung et al. 2012; Chaowana and Barbu 2017), rice (Wang et al. 2010; Chen et al. 2015), palm (Abu-Sharkh and Hamid 2004), straw (Yaacab et al. 2016), broom (Nouar et al. 2020) can be given. Human hair (Verma and Singh 2016), alpaca hair (Fortunati et al. 2015), sheep wool (Aluigi et al. 2014), chicken feather (Akderya et al. 2020) can be used as a reinforcement element

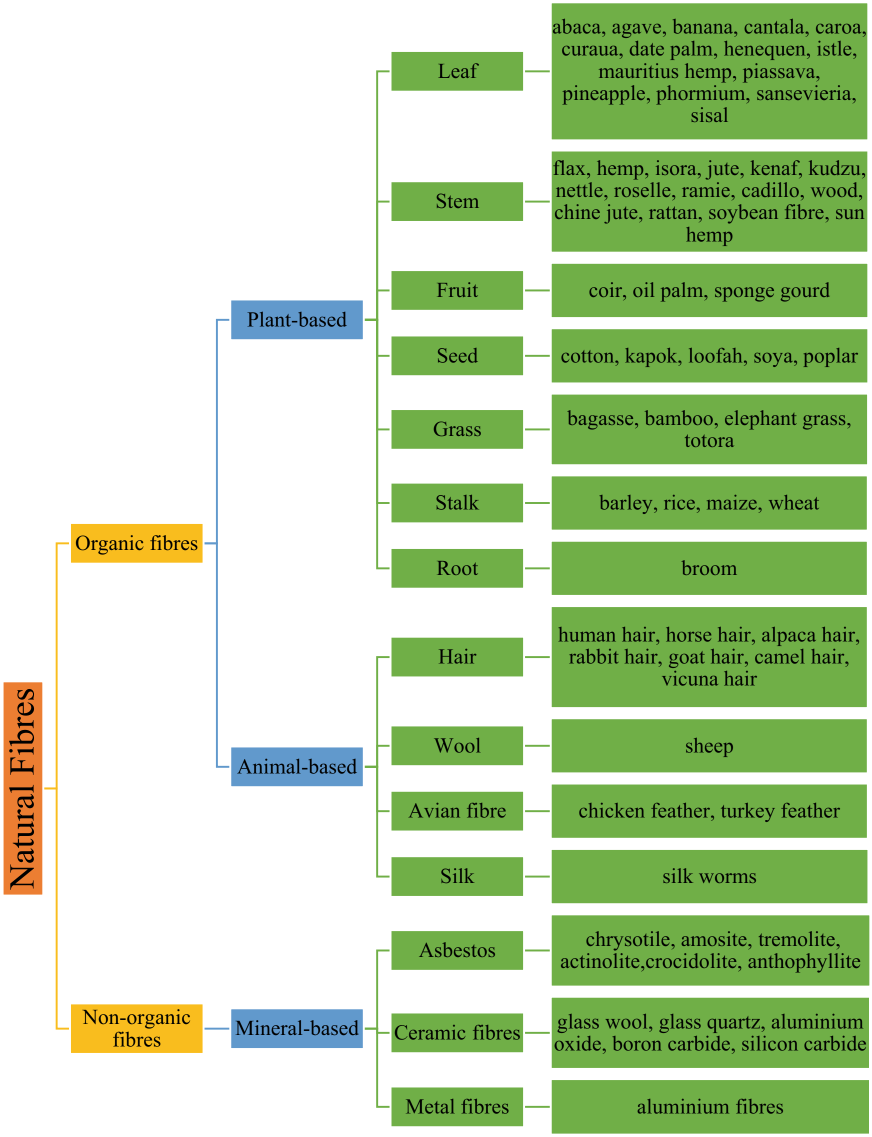

Fig. 1 Classification of natural fibres and their origins (Riedel and Nickel 2002; John and Thomas 2008; Tridico 2009; Chandramohan and Marimuthu 2011; Akil et al. 2011; Azwa et al. 2013; Pandey et al. 2015; Bharath and Basavarajappa 2016; Sapuan et al. 2017; Mayandi et al. 2018; and Hiremath 2020; Hiremath and Sridhar 2020)

from animal-based fibres. Non-organic mineral-based natural fibres can be evaluated in three groups: asbestos, ceramic fibres, and metal fibres. Chrysotile, amosite, tremolite, actinolite, crocidolite, and anthophyllite are examples of asbestos class (Lang et al. 1986; Rinaudo et al. 2005), glass wool, glass quartz, aluminium oxide, boron carbide, and silicon carbide are in the ceramic fibre class, and in addition to those, aluminium fibre can be given as an example of metal fibre class (Chandramohan and Marimuthu 2011; Sapuan et al. 2017).

There has been a noticeable increase in the trend of use of bio-composite materials in recent years. In this direction, scientific studies are carried out to detect the changes in bio-composites' properties in outdoor conditions to determine their shelf life. There are harsh environmental conditions that all materials can be exposed to in outdoor conditions. These conditions include acid rain, variable temperatures, high and low temperatures, wind, solar radiation, oxygen, biotic factors, and humidity. Natural weathering environment conditions are illustrated in Fig. 2. External conditions may cause degradation in the material and leakage of additives in its structure and entry of additives that are not in its structure. (Yew et al. 2009; Badji et al. 2018a; Liu et al. 2020; González-López et al. 2020).

Some researchers focused on the behaviour of natural fibre-reinforced bio-composite materials in different environmental conditions. Duigou et al. (2011) conducted a study to determine how to protect the external layers of flax/poly (l-lactic acid) (PLLA) bio-composite material from seawater ageing. Another study was carried out by Duigou et al. (2014) to obtain the effects of long-term seawater ageing on the flax/poly (lactic acid) (PLA) bio-composite. Ogunsona et al. (2017) investigated the behaviour of biocarbon reinforced nylon bio-composites under accelerated hydrothermal ageing conditions. Lila et al. (2019) conducted a study in which

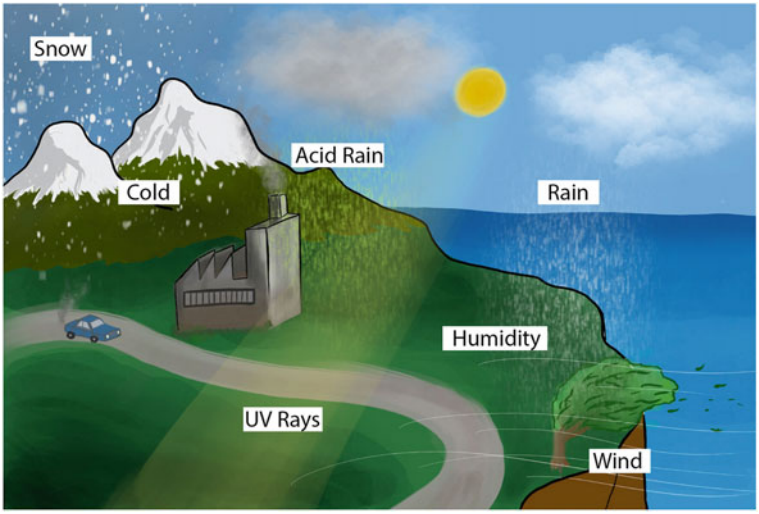

Fig. 2 Natural weathering conditions diagram

they examined the behaviour of bagasse fibre/PLA bio-composites under accelerated thermal ageing. The study on the differences between the bio-composite properties using pineapple leaf and palm fibre as reinforcement elements and polypropylene as a matrix was carried out by Chollakup et al. (2017). When the results of these studies were examined, it is seen that bio-composites degraded due to reasons such as matrix cracking, swelling, hydrolysis, debonding of fibre/matrix, and high-water uptake as a result of exposure to severe environmental conditions.

2 Natural Weathering Conditions

The high sensitivity of bio-composites to climatic conditions constitutes uncertainty and obstacle for their usage conditions. A limited number of scientific studies (Badji et al. 2018a, b, c; Abdullah et al. 2019) have been conducted to gain insight into bio-composites' durability and behaviour under natural weathering conditions with different climatic conditions (Badji et al. 2018d). With natural weathering, more than one external environmental factors synergistically affect the material at the same time. In the natural weathering environment, it cannot be precisely known what factor causes the dramatic changes in the material's properties (Badji et al. 2018d). The biggest reason for the application of natural weathering technique on materials is to obtain reliable and realistic results for the behaviour of the material in real-life conditions (Pospíšil et al. 2006; Lv et al. 2015; González-López et al. 2020).

The most influential factors that cause degradation of both polymer matrix and natural fibre in bio-composite materials exposed to natural weathering environment are high temperatures or oxidative processes caused by free radicals due to ultraviolet (UV) rays, and degradation phenomena bring about decrease in physicochemical properties of bio-composites (Stark and Matuana 2004; Fabiyi et al. 2008; Badji et al. 2018d). The polymer matrix undergoes Norrish type I and II reactions chain scissions (Parikh et al. 2006) during natural weathering exposure and transforms into lower molecular weight products (Stark and Matuana 2004; Fabiyi et al. 2008; Thirmizir et al. 2011; Badji et al. 2018d). In addition to Norrish type reactions, degradation phenomena cause effects in the matrix, such as absorption of UV rays by the lignin substance, photo-yellowing effect, and quinoid structure formation. Moreover, degradation phenomena cause chromophoric groups' formation in plant-based natural fibres (Beg and Pickering 2008; Azwa et al. 2013; and Hiremath 2020; Siakeng et al. 2020).

3 Results

3.1 Effects on Mechanical Properties

Having knowledge about the mechanical behaviour of materials gives a chance to intervene with a proactive approach to prevent malfunctions and errors that can potentially occur in engineering applications. Few scientific studies have been done to reveal the behavioural changes in bio-composites' mechanical properties in natural weathering environments.

Changes in some bio-composites' mechanical properties after exposure to natural weathering such as flexural strength, flexural modulus, tensile strength, tensile modulus, elongation at break, hardness and impact strength are given in Table 1. According to this table, most of the mechanical properties have decreased with natural weathering environments. The decrease in hardness values results from polymer chain scissions due to surface cracks and embrittlement occurring in natural weathering environment (Du et al. 2010). With the extension of the natural weathering duration, the number of chain scissions increase. Increasing the number of chain scissions results in the formation of shorter polymer chains and therefore, a decrease in overall mechanical properties (Fabiyi et al. 2008). Stark and Matuana (Stark et al. 2004; Stark and Matuana 2006) attributed the decrease in flexural strength values the fact that the crystallinity of composites increases at the beginning of the exposure period due to UV light and water exposure encountered in the natural weathering environment and decreases with the prolongation of this period. At the beginning of the exposure, the shorter and more mobile chains recrystallise. With the prolongation of the exposure, the chain scissions continue, and thus, the crystal regions are affected, and the crystallinity decreases.

The decrease in mechanical strength properties has been associated with the deterioration of the composite material's structure and properties. Natural weathering environment causes the composite materials to deteriorate, thus weakening the matrix-filler interfacial bonding. The swelling and shrinkage of natural fibres or particles with hydrophilic capability by absorbing and desorbing moisture cause the quality of the matrix-filler interface bonding to decrease (Beg and Pickering 2007, 2008). Stress concentration and chain scissions forming a brittle layer on the matrix surface, and the degradation of fillers led to an increase in composite materials' brittleness. Natural fibres deteriorating due to long-term natural weathering causes chromophoric groups to form in the composite material. These groups increased the photooxidation of composites. Moreover, thanks to photodegradation, additives with lignin in their structure have led to the formation of free radicals. Free radicals have had a detrimental effect on the structure of the matrix material by increasing chain scissions' speed (Beg and Pickering 2007; Naumann et al. 2012; Zhou et al. 2016).

The decrease in matrix-fibre interfacial bonding success of naturally weathered and therefore degraded composite materials may be caused by the inability to distribute the energy generated at the moment of impact through vibration and

Table 1 Mechanical properties of naturally weathered bio-composites

Study done by	Natural Weathering Site	Duration	Material	Mechanical Properties			
Homkhiew et al. (Homkhiew et al. 2014)	Hat Yai, Songkhla, Thailand	One year	Rubberwood flour reinforced polypropylene	**Maximum strain (%)**	**Hardness (Shore D)**	**Flexural strength (MPa)**	**Flexural modulus (GPa)**
			Neat polypropylene	6.95 to 2.26 76.25% ↓	75.6 to 65.9 12.82% ↓	50.1 to 28.6 42.85% ↓	1.67 to 0.97 23.22% ↓
			25% rubberwood flour reinforced polypropylene	3.99 to 3.53 11.29% ↓	76.4 to 72.3 5.32% ↓	44.3 to 42.5 4.09% ↓	1.93 to 1.73 10.26% ↓
			45% rubberwood flour reinforced polypropylene	2.36 to 2.04 13.39% ↓	78.3 to 74.8 4.47% ↓	43.4 to 39.5 8.95% ↓	2.66 to 2.23 16.30% ↓
Popa et al. (Popa et al. 2013)	Massa Martana, Perugia, Italy	600 hours	Hemp shives reinforced polypropylene	**Tensile strength (MPa)**	**Elongation at break (%)**	**Young modulus (GPa)**	**Charpy impact strength (kJ/m²)**
			60% hemp shives reinforced polypropylene	28.9 to 25.3 %12.46 ↓	2.1 to 16.2 %671.43 ↑	1.99 to 2.3 %15.58 ↑	7.49 to 3.74 %50.01 ↓
Zhou et al. (Zhou et al. 2016)	Fuzhou, China	One year	Bamboo powder reinforced polypropylene foam	**Tensile strength (MPa)**	**Flexural modulus (GPa)**	**Flexural strength (MPa)**	**Notched impact strength (kJ/m²)**
			33% bamboo powder reinforced polypropylene foam	22.23 to 20.08 %9.67 ↓	2.80 to 2.52 %10.00 ↓	41.75 to 40.50 %2.99 ↓	6.19 to 5.16 %16.64 ↓
Astadini et al. (Astadini et al. 2020)	Surakarta, Indonesia	Two months	Bamboo reinforced polyethylene	**Tensile strength (MPa)**	**Elongation at break (%)**	**Young modulus (MPa)**	**Charpy impact strength (kJ/m²)**
			20% bamboo reinforced polyethylene	20.30 to 21.35 5.17% ↑	0.26 to 0.29 11.54% ↑	234.85 to 110.61 47.01% ↓	3.39 to 2.95 12.98% ↓
Badji et al. (Badji et al. 2018d)	Pau, Southwest of France	12 months	Hemp fibres reinforced polypropylene	**Elastic modulus (MPa)**	**Flexural strength (MPa)**	**Flexural strain (%)**	
			Neat polypropylene	1922 to 1750 8.95% ↓	71.61 to 46.61 34.91% ↓	5 to 3.5 30.00% ↓	

(continued)

Table 1 (continued)

Study done by	Natural Weathering Site	Duration	Material	Mechanical Properties			
			10wt% hemp fibres reinforced polypropylene	2702 to 2435 9.89% ↓	79.62 to 66.23 16.82% ↓	Same	
			30wt% hemp fibres reinforced polypropylene	4685 to 3734 20.30% ↓	88.57 to 72.45 18.20% ↓	Same	
del Pilar Fajardo Cabrera de Lima et al. (del Pilar Fajardo Cabrera de Lima et al. 2020)	Porto Alegre, Brasil	One year	Bamboo fibre reinforced polypropylene	**Tensile stress at break (MPa)**	**Elongation at break (%)**	**Elasticity Module (GPa)**	**Izod impact strength (kj/m²)**
			30% bamboo fibre reinforced polypropylene	12.45 to 7.80 37.35% ↓	0.99 to 0.80 19.20% ↓	1.40 to 0.85 39.29% ↓	11.00 to 7.80 29.01% ↓
Soccalingame et al. (Soccalingame et al. 2016)	Alès, Gard, France	One year	Wood flour reinforced polypropylene	**Tensile yield strength (MPa)**	**Tensile elongation at yield (%)**	**Charpy impact strength (kJ/m²)**	
			Neat polypropylene	39 to 16 58.97% ↓	7 to 1 85.71% ↓	No break to 1	
			10% wood flour reinforced polypropylene	39 to 32 17.95% ↓	4 to 3 25.00% ↓	17 to 2 88.24% ↓	
			30% wood flour reinforced polypropylene	43 to 37 13.95% ↓	Same	9 to 6 33.33% ↓	
Chan et al. (Chan et al. 2019)	Queensland, Australia	One year	Wood flour reinforced polyhydroxyalkanoate, wood flour reinforced poly(lactic acid), wood flour reinforced polyethylene	**Tensile strength (MPa)**	**Elongation at break (%)**	**Tensile modulus (GPa)**	
			Neat polyhydroxyalkanoate	31.98 to 33.32 4.19% ↑	8.81 to 5.37 39.05% ↓	2.57 to 3.18 23.74% ↑	
			20% wood flour reinforced polyhydroxyalkanoate	29.30 to 24.49 16.42% ↓	2.21 to 1.38 37.56% ↓	4.48 to 3.71 17.19% ↓	

(continued)

Table 1 (continued)

Study done by	Natural Weathering Site	Duration	Material	Mechanical Properties			
			50% wood flour reinforced polyhydroxyalkanoate	21.39 to 12.57 41.23% ↓	0.87 to 0.95 9.20% ↑	5.28 to 2.67 49.43% ↓	
			50% wood flour reinforced poly(lactic acid)	27.81 to 10.01 64.01% ↓	0.90 to 0.62 31.11% ↓	4.28 to 2.09 51.17% ↓	
			50% wood flour reinforced polyethylene	12.03 to 5.94 50.62% ↓	1.22 to 0.94 22.95% ↓	2.25 to 1.32 41.33% ↓	
Thirmizir et al. (Thirmizir et al. 2011)	Penang, Malaysia	Six months	Kenaf bast fibres reinforced poly(butylene)	**Flexural strength (MPa)**	**Flexural modulus (GPa)**		
			Neat poly(butylene)	36.69 to 20.00 %45.49 ↓	0.61 to 0.73 19.67% ↑		
			10wt% kenaf bast fibres reinforced poly(butylene)	36.90 to 27.11 %26.53 ↓	1.16 to 0.92 20.69% ↓		
			20wt% kenaf bast fibres reinforced poly(butylene)	37.46 to 21.33 %43.06 ↓	2.59 to 1.12 56.76% ↓		
			30wt% kenaf bast fibres reinforced poly(butylene)	41.13 to 17.32 %57.89 ↓	3.13 to 1.95 37.70% ↓		
			40wt% kenaf bast fibres reinforced poly(butylene)	39.65 to 14.30 %63.93 ↓	3.25 to 1.34 58.77% ↓		
Abu-Sharkh and Hamid (Abu-Sharkh and Hamid 2004)	Dhahran, Saudi Arabia	Nine months	Date palm fibre reinforced polypropylene	**Tensile strength (MPa)**	**Elongation at break (%)**		
			Neat polypropylene	33.40 to 17.13 48.71% ↓	11.18 to 3.32 29.70% ↓		
			29% date palm fibre reinforced polypropylene	27.73 to 24.67 11.03% ↓	4.42 to 4.50 1.81% ↑		
	Lappeenranta, Finland	One year	Wood fibre reinforced polypropylene	**Charpy impact strength (kJ/m^2)**			

(continued)

Table 1 (continued)

Study done by	Natural Weathering Site	Duration	Material	Mechanical Properties			
Butylina et al. (Butylina et al. 2012)			70% wood fibre reinforced polypropylene (control sample)	3.16 to 3.02 4.43% ↓			
Rahman et al. (Rahman et al. 2011)	Johor, Malaysia	Four months	Rice husk reinforced polyethylene	**Impact strength (kJ/m^2)**			
			30% rice husk reinforced polyethylene	7.44 to 5.63 24.33% ↓			

the inability to spread this energy in weak matrix-fibre regions (Oksman et al. 2009; Rahman et al. 2011).

3.2 Effects on the Thermal Properties

Exposure to natural weathering conditions has caused some changes in the thermal properties of composite materials. These changes are given in Table 2, as revealed by some scientific studies. The decrease in the first melting temperature of naturally weathered composites indicates the degradation of the matrix's lamellar fold surfaces, and the decrease in the second melting temperature indicates the effect of decaying molecules on crystal phase formation. The smaller and more defective molecules in the crystals formed during the recrystallisation process are the reason for the decrease in the second melting temperature (Rabello and White 1996, 1997; Butylina et al. 2012). Under natural weathering conditions, changes occurring on the matrix's lamellar structure due to cross-linking with UV rays' effect may affect the mechanical properties, while the melting temperatures may remain unchanged if they do not affect the bulk properties of the matrix. In case of exposure to high energy levels such as gamma-ray or electron irradiation, chain scissions and cross-linking in the amorphous phase cause changes in the bulk crystal structure of the composite material, and thus a decrease in the peak melting temperature is observed (Mitomo et al. 1994; Bergmann et al. 2007; Wei and McDonald 2016; Chan et al. 2019).

Photodegradation appears to be more predominant in the amorphous phase whose molecular chain is susceptible to further crystallisation; however, the crystallinity's overall decrease indicates that the crystalline phase is generally affected (Stark and Matuana 2006; Homkhiew et al. 2014; Badji et al. 2018a). One of the reasons for the decrease in crystallinity may be the impurities caused by factors such as dust and moisture accumulating in the composite material during exterior natural weathering exposure or the presence of smaller and more defective molecules in the material (Butylina et al. 2012; Soccalingame et al. 2016). The increase in the degree of crystallinity under natural weathering conditions may result from the change in molecular weight due to degradation of the polymer of the composite leading to chain breakage and subsequent secondary crystallisation (Fabiyi and McDonald 2014).

3.3 Effects on the Aesthetics

Some alterations in lightness and colours have been observed as a result of factors such as high temperature, UV rays and rain, with the exposure of composite materials to natural weathering conditions for specific periods. Total colour change is calculated by taking the lightness, redness and yellowness values of the composite into consideration. The changes in the visual properties of composites under natural weathering conditions are given in Table 3. When Rahman et al. (2011) exposed the

Table 2 Thermal properties of naturally weathered bio-composites

Study done by	Natural Weathering Site	Duration	Material	Thermal Properties			
Butylina et al. (Butylina et al. 2012)	Lappeenranta, Finland	One year	Wood fibre reinforced polypropylene	**First melting temperature (°C)**	**Second melting temperature (°C)**	**Crystallisation temperature (°C)**	**Crystallinity (%)**
			70% wood fibre reinforced polypropylene (control sample)	164 to 155 5.49% ↓	164 to 144 12.20% ↓	120 to 115 4.17% ↓	65.15 to 54.55 16.27% ↓
Badji et al. (Badji et al. 2018a)	Pau, Southwest of France	One year	Hemp fibres reinforced polypropylene	**Crystallinity rate from first heating step (%)**	**Crystallinity rate from the second heating step (%)**		
			Neat polypropylene	45.89 to 44.00 4.12% ↓	50.85 to 46.65 8.26% ↓		
			10wt% hemp fibres reinforced polypropylene	45.90 to 42.92 6.49% ↓	50.80 to 47.92 5.67 ↓		
			30wt% hemp fibres reinforced polypropylene	46.93 to 35.05 25.31% ↓	52.55 to 41.89 20.29% ↓		
Soccalingame et al. (Soccalingame et al. 2016)	Alès, Gard, France	One year	Wood flour reinforced polypropylene	**Crystallinity rate from first heating step (%)**	**Crystallinity rate from the second heating step (%)**		
			10% wood flour reinforced polypropylene	46.0 to 45.5 1.09% ↓	50.7 to 43.6 14.00% ↓		
			30% wood flour reinforced polypropylene	42.3 to 37.8 10.64% ↓	46.9 to 43.4 7.46% ↓		

(continued)

Table 2 (continued)

Study done by	Natural Weathering Site	Duration	Material	Thermal Properties			
Chan et al. (Chan et al. 2019)	Queensland, Australia	One year	Wood flour reinforced polyhydroxyalkanoate	**Peak melting temperature (°C)**	**Melt crystallisation temperature (°C)**		
			Neat polyhydroxyalkanoate	173.77 to 172.33 0.83% ↓	112.39 to 116.45 3.61% ↑		
			20% wood flour reinforced polyhydroxyalkanoate	172.14 to 172.21 0.04%	109.70 to 122.67 11.82% ↑		
			50% wood flour reinforced polyhydroxyalkanoate	169.29 to 170.09 0.47%	105.88 to 119.70 13.05% ↑		
Hung et al. (Hung et al. 2012)	Taichung City, Taiwan	Three years	Bamboo fibres reinforced high-density polyethylene	**Crystallinity (%)**			
			60% bamboo fibres reinforced high-density polyethylene	53.88 to 82.76 53.60% ↑			
Akderya et al. (Akderya et al. 2020)	Manisa, Turkey	Five years	Chicken feather fibre reinforced poly(lactic acid)	**Melting temperature (°C)**	**Crystallinity (%)**		
			Neat poly(lactic acid)	153.15 to 150.00 2.06% ↓	29.26 to 3.14 89.27% ↓		
			2% chicken feather fibre reinforced poly(lactic acid)	154.65 to 155.07 0.27%	4.50 to 6.79 50.89% ↑		
			5% chicken feather fibre reinforced poly(lactic acid)	155.75 to 155.49 0.17%	3.74 to 4.98 33.16% ↑		
			10% chicken feather fibre reinforced poly(lactic acid)	155.15 to 155.66 0.33%	2.52 to 6.11 142.46% ↑		
del Pilar Fajardo Cabrera de Lima	Porto Alegre, Brasil	One year	Bamboo fibre reinforced polypropylene	**Melting temperature**	**Crystallinity (%)**		

(continued)

Table 2 (continued)

Study done by	Natural Weathering Site	Duration	Material	Thermal Properties			
et al. (del Pilar Fajardo Cabrera de Lima et al. 2020)				**(°C)**			
			30% bamboo fibre reinforced polypropylene	165 to 166 0.61%	50.89 to 43.41 14.70% ↓		
Abu-Sharkh and Hamid (Abu-Sharkh and Hamid 2004)	Dhahran, Saudi Arabia	Nine months	Date palm fibre reinforced polypropylene	**Melting temperature (°C)**			
			Neat polypropylene	163.46 to 155.52 4.86% ↓			
			29% date palm fibre reinforced polypropylene	162.25 to 161.33 0.57%			
Fabiyi and McDonald (Fabiyi and McDonald 2014)	Moscow, Idaho, USA	Four months	Pine fibre reinforced polypropylene	**Crystallinity (%)**			
			60% pine fibre reinforced polypropylene	38.43 to 41.99 9.26% ↑			

Table 3 Aesthetics of naturally weathered bio-composites

Study done by	Natural Weathering Site	Duration	Material	Colour measurements			
Zhou et al. (Zhou et al. 2016)	Fuzhou, China	One year	Bamboo powder reinforced polypropylene foam	**Lightness (L*)**	**Redness (a*)**	**Yellowness (b*)**	**The colour change (ΔE*)**
			33% bamboo powder reinforced polypropylene foam	27.82 to 50.39 ΔL: 22.57 ↑	1.11 to -2.40 Δa: -3.51 ↓	4.78 to 4.88 Δb: 0.10	22.80
Thirmizir et al. (Thirmizir et al. 2011)	Penang, Malaysia	Six months	Kenaf bast fibres reinforced poly(butylene)	**Lightness (L)**	**Redness (a*)**	**Yellowness (b*)**	**The colour change (ΔE*)**
			Neat poly(butylene)	70.25 to 74.12 ΔL: 3.87 ↑	-1.45 to -1.80 Δa: -0.35 ↓	3.47 to 5.33 Δb: 1.86 ↑	4.30
			10wt% kenaf bast fibres reinforced poly(butylene)	36.12 to 47.51 ΔL: 11.39 ↑	1.84 to 1.28 Δa: -0.56 ↓	7.30 to 6.18 Δb: -1.12 ↓	11.46
			20wt% kenaf bast fibres reinforced poly(butylene)	32.50 to 49.37 ΔL: 16.87 ↑	2.09 to 0.88 Δa: -1.21 ↓	6.76 to 5.75 Δb: -1.01 ↓	16.94
			30wt% kenaf bast fibres reinforced poly(butylene)	29.16 to 53.48 ΔL: 24.32 ↑	1.96 to 0.49 Δa: -1.47 ↓	6.21 to 5.30 Δb: -0.91 ↓	24.38
			40wt% kenaf bast fibres reinforced poly(butylene)	28.38 to 54.82 ΔL: 26.44 ↑	1.82 to -1.16 Δa: -2.98 ↓	5.69 to 4.72 Δb: -0.97 ↓	26.48
Wang et al. (Wang et al. 2010)	Harbin city, Heilongjiang Province, China	Two years	Rice-hull powder reinforced polyethylene	**Lightness (L*)**	**The colour change (ΔE*)**		
			50% rice-hull powder reinforced polyethylene (red lumber)	32.88 to 41.49 ΔL: 8.61 ↑	12.8		
			50% rice-hull powder reinforced polyethylene (yellow lumber)	49.24 to 60.91 ΔL: 11.67 ↑	9.2		
Study done by	**Natural Weathering Site**	**Duration**	**Material**	**Colour measurements**			
Rahman et al. (Rahman et al. 2011)	Johor, Malaysia	Four months	Rice husk reinforced polyethylene	**Lightness (L*)**	**The colour change (ΔE*)**		
			30% rice husk powder reinforced polyethylene	47.54 to 58.26 ΔL: 10.72 ↑	11.67		

polyethylene reinforced with 30% rice husk powder composite to natural weathering environment for four months, it caused a colour change in the composite as a result of photooxidation on the sample surfaces. Rain, which is one of the factors of natural weathering environment, accelerates the erosion process on the composite material's surface and is a source of moisture that can cause dimensional changes. Typical surface erosion spreads faster in materials such as wood-based materials with low density, and the surface of the material becomes rougher as a result of this spread. Surface erosion spread is a slowly progressing process and does not show itself in short periods (Rahman et al. 2011).

4 Future Perspective

Bio-composite materials are new trend materials that are being used as an alternative to traditional materials in a wide variety of industrial and engineering applications. Increased awareness and interest in long-term sustainability and environmental sensitivity, as well as superior properties such as high specific strength, high hardness values, higher fatigue strength, impact absorption, superior resistance to corrosion, recyclability, non-toxicity, and low-cost cause bio-composites to be evaluated in the class of engineering materials, and it is predicted that their frequency of use will increase in the future. Static and dynamic failures such as matrix cracking, fibre breakage and layer delamination, high sensitivity to climatic conditions and the inability to predict the mechanical behaviour of natural fibre reinforced composites present challenges in predicting the reliable performance of bio-composites. In order for the components of bio-composite materials to be selected correctly, long-term reliable performance must be determined. For this purpose, real-time experimental studies in natural weathering environment and accelerated weathering studies on bio-composites are mandatory to carry out. There is a need to develop new combined evaluation criteria in both macro and nano scale by demonstrating consistency between these studies.

5 Conclusion

Bio-composites encounter factors such as humidity, high and low temperatures, radiation and UV rays in natural environments. These factors cause deterioration in the mechanical, and thermal properties and aesthetics of bio-composite materials. Mechanical properties such as flexural strength, tensile strength, modulus of elasticity, elongation at break, impact resistance change with influences such as chain scissions and reduction of fibre-matrix interfacial bonding success. Thermal properties such as crystallinity and melting temperature deteriorate with recrystallisation, resulting in the formation of smaller and more defective molecules. Aesthetic properties such as lightness, surface roughness and shape also change with effects such as photooxidation, moisture absorption and photodegradation.

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