Animal Wastes as Thermoplastic Composite Reinforcement Materials for Sustainable Development

A. K. Issa, M. H. Idris, M. I. Tikau

***Abstract:** Nowadays solid wastes are becoming serious environmental challenges in Africa and most especially in Nigeria. Many strategies that are employed by local, state and federal government to curb the situation are always sabotaged due to poor altitude to waste management and corruption. Among these solid wastes are animal waste viz: chicken feather, animal horn, hoof, bone and hair (wool), human hair, silk and so on. These wastes contain keratin and collagen which make them viable for reinforcement materials in developing thermoplastic composite apart from their lighter weight, availability and bio-degradability. This paper presents review on utilization of animal waste as workable fibre to synthetic fibres which are not recyclable and biodegradable. Furthermore, it provides some important data that can facilitate the usage of these animal fibres in order to achieve both economic and social sustainable development.*

***Keywords:** Animal fibre, Fibre-reinforced, Mechanical properties, thermoplastic*

I. INTRODUCTION

Animal fibre is generally addressed as a waste product and their disposals are causing a serious harm to environment. The two major methods that are conveniently used in disposing them are burning and burying. Both pose risk to humans, plants and ecosystems. Generally, animal fibre contains protein, such as keratin and collagen [1]. Traditionally animal fibre is categorized into animal hair, silk fibre and avian fibre as shown in fig. 1. Animal hairs are hairs obtained from animals and hairy mammals, such as human hair, sheep hair (wool), goat hair, alpaca hair, horse hair, etc. Silk fibre is gotten from dried saliva of insect or creeping or crawling invertebrate or insects for the period of preparation of cocoons for protection. Examples are silk from silk worms, spiders, termites, etc. Avian fibre is taken from creatures that covered with feather, e.g. chicken feather [2]. Recently, animal fibres are also gotten from other parts of animals which contain protein too, such as Oxen horn, cow horn, hoof and bone, etc [3] [4]. These fibres are useful in reinforcing composite material and perform even better than plant fibres in some area of applications due to their ability to offer a high strength-to-weight ratio, high impact resistance, corrosion and termite resistance. In addition, animal fibre composite materials can be modified or tailored to adapt or meet the specific purpose and application [5].

Thermoplastic composite is the combination of thermoplastic matrix with any reinforcement fibre. This also falls under polymer matrix composite. Thermoplastic composite is superior to its counterpart in terms of recyclability, ductility and impact resistance, weldability with different welding techniques, such as resistance welding, vibration welding and ultrasonic welding, and lower processing time because it does not involve any chemical reaction in the mold [6].This paper presents review on Animal wastes as thermoplastic composite reinforcement materials for sustainable development.

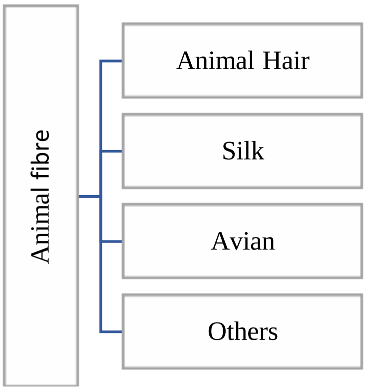

Fig. 1: Types of Animal fibre

II. ANIMAL FIBRE

A. Characteristics/Properties of Animal Fibre

Animal fibres possess some important characteristics which make them suitable for many engineering composite applications. Table I shows unique characteristics of wool, silk, human hair, feather, horn and their areas of applications.

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Table I: Characteristics/ Properties of Some Selected Animal Fibre

Animal fibre	Characteristics/properties	Applications	References
Wool	Excellent Elongation Excellent recovery Poor heat conductivity Excellent resilience More hygroscopic Shape stability High alkali sensitivity Fair bacteria resistance Less inflammable, low solubility, excellent retardant.	Textile industry, building industry, water filter, technical insulation, carpet.	[7] [8]
Silk	Losses up to 20%strength when wet Good moisture regains up to 11% Poor-moderate elasticity Weaken if exposed to much light Excellent tensile strength	Textile industry, Tissue engineering application.	[9]
Human hair	High tensile strength High elasticity High durability Good resistance to stretching Resistance to hydraulic power Slow degradation rate Thermal insulation	Clay reinforcements, fabric making, oil filter, lining ovens, ropes, cosmetic brushes, oil water separation, engineering polymer.	[10] [11] [4][12] [13]
Feather	Low density Acceptable specific strength High water resistance	Fluid absorbent, Insulation application.	[14] [15]
Horn	High in toughness High impact resistance High resilience Good energy absorption Good resistance to fracture	handles, buttons, horn belt buckles, horn drinking vessels.	[16] [17]

B. Mechanical Properties of Animal Fibre

When recommending any material for any engineering application, data regarding the mechanical properties of that material have to be known. Thus, table II below indicates young modulus and tensile strengths of some animal fibres.

Table II: Mechanical Properties of Animal Fibre

Animal fibre	Young Modulus (GPa)	Tensile Strength (Mpa)	References
Wool	2.3-3.4	120-174	[18]
Silk Spider silk B. mori silk Twisted B. silk Tussah silk	11-13 16 6.10 3.82 5.79	875-972 650-750 208.45 156.27 248.7	[18] [1]
Human hair	1.5 1.74-4.39	200	[10]
Feather rachis at 0%RH Feather rachis at 100%R.H Chicken feather Bird Bird (grey heron)	3 2.50 1.78	221 106 70	[19]
Horn (big horn sheep) Horn (Cattle) Horn (Oxen)	1.5 2.2 0.81	127b 39b 60-159.5 41.86	[16] [17]
Hoof (Bovine)	0.4	16.2	[20]
Hoof (Equine)	2.6	38.9	[20]

III. THERMOPLASTIC RESIN

Thermoplastic resin comprises of long, disconnected molecules that change to a viscous liquid at the processing temperature, typically (260° to 371^{o}C), and, after forming, are cooled to an amorphous, semi-crystalline, or crystalline solid.

The process of thermoplastics is reversible, thus they are sustainable matrix, although this resin has disadvantages of low crack and impact resistance and low temperature strength but with the ability of fibre reinforcement, these deficiencies can be overcome either by heating the mold prior to pouring of molten polymer to the mold or providing the molten polymer in excess.
Thermoplastic matrix can be categorized into amorphous, crystalline and semi crystalline matrix as shown in fig.2.

A. Amorphous Thermoplastic Matrix

In amorphous, constituent molecules are arranged randomly and usually transparent in nature. Examples are poly phenylene oxide (PPO), Poly carbonate (PC) and acrylonitrile butadiene styrene [21]. It has advantages of dimensional stability, lower mold shrinkage than crystalline coupling with potential for application in structural foam. But the drawbacks of this type are faster wear abrasion, lower fatigue resistance and higher process time when compared to crystalline [22].

B. Crystalline Thermoplastic Matrix

In crystalline, constituent molecules are arranged in a regular and symmetrical order and usually translucent in nature. Examples are low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP) and nylon [21]. This has benefits of good solvent, fatigue and wear resistance, higher design strain than amorphous, temperature can be improved by fibre reinforcements. However, higher and variable shrinkage, poor adaptation to adhesion and higher creep are their weakness [22].

C. Semi-crystalline Thermoplastic Matrix

This harmonizes the properties of crystalline polymers and amorphous [23]. Examples of this group are polyester polybutylene terephthalate (PBT) and polyamide Imide (PAI) [21].

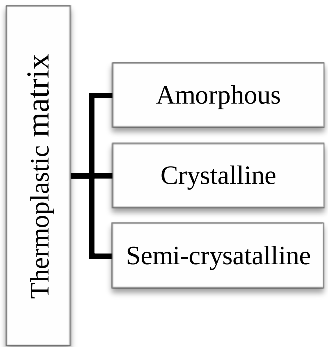

Fig. 2: Classification of Thermoplastic Matrix

Furthermore, Major prime movers to the current use of thermoplastic resin are recyclability, then its density and tensile modulus (resistance of materials to elastic deformation). Also glass transition temperature is another key factor, most importantly when processing polymer. Table III below presents density, glass transition temperature, tensile strength and tensile modulus for some thermoplastic based matrix materials [21].

Table III: Properties of Thermoplastic Matrix

		Thermoplastic matrix materials					
Properties	Limits	PP	LDPE	HDPE	PC	PBT	PAI
$\rho(\frac{g}{cm^3})$	Upper	0.920	0.925	1.000	1.24	1.35	1.45
	Lower	0.899	0.910	0.910	1.19	1.23	1.38
T_g	Upper	-10	-125	-100	150	45	290
	Lower	-23	----	-133	140.5	20	244
$\sigma_{max}(MPa)$	Upper	41.4	78.6	38	72	55.9	192
	Lower	26	4	14.5	53	51.8	90
$E(GPa)$	Upper	1.776	0.38	1.490	3	2.37	4.4
	Lower	0.95	0.055	0.413	2.3	----	2.8

Source [21]

IV. PAST WORK ON ANIMAL FIBRE BASED REINFORCED THERMOPLASTIC COMPOSITE

Mechanical Properties and Tribological Behavior of Recycled Polyethylene/Cow Bone Particulate Composite were studied by [3]. In their study low density polyethylene was used as matrix, cow bone particle was varied from 5%wt to 25%wt at interval of 5%wt. Mechanical properties, such as tensile and impact strengths, hardness, rigidity and wear rate, were tested on different five samples. The results revealed that the higher the amount of percentage weight of cow particle, the higher the hardness and tensile strength but the lower the rigidity, impact strength and wear rate. Therefore, cow bone particles can be used to improve the strength and wear properties of recycled low-density polyethylene (RLDPE) composite. Besides, Isiaka and Temitope [24] investigated the influence of cow bone particle size distribution on the mechanical properties of cow bone reinforced polyester composite. Cow particle sizes of 75, 106, 300µm with different weights of these particle sizes ranging from 2% to 8% at interval of 2% were used to reinforce polyester. Hardness, toughness and tensile and flexural tests were performed on the samples. It was observed from the results that sample with 8%wt of 75µm particle size was able to enhance tensile and flexural strengths than the others while samples with 6-8% of 300µm were able to enhance the toughness which means that coarse particles of cow bone can be used to improve the toughness while its fine particle can be used to improve the strength. Mechanical and thermal properties of horn fibre (HF) reinforced polypropylene composites were examined by [4]. In their study four different weights (5%, 10%, 15% and 20%) of particles of Oxen horn were used to reinforce polypropylene.

Samples of the composites developed were tested for tensile, flexural and impact strengths. The results were compared with mechanical properties of pure Oxen horn and pure polypropylene. It was observed that there was increment in tensile yield strength, tensile modulus, flexural strength and flexural modulus of HF/PP composites as compared to those of pure PP, but with reduction in their ultimate tensile and impact strengths.

The tensile strength for each of the random oriented human hair fibre reinforced polyester composites developed was determined by [10]. Different fibre lengths and loadings were used to produce the samples. Sample reinforced with 30mm fibre length and that of 20% fibre loading were having the highest tensile strengths. Also, wool reinforced polypropylene composites using extrusion process, were developed by [8]. In which different fibres weight contents were mixed with the matrix and maleic anhydride polypropylene (MAPP) grades as compatibilizer for interfacial bonding improvements. Tensile modulus, tensile strength and horizontal burning tests were conducted on the composites in order to determine the strength and fire retardant of the composites. Results showed that wool fibre was able to increase the tensile modulus of the composites. However, the tensile strength was generally lower relatively to Pure PP matrix excluding the 15wt% wool fibre and 4wt% MAPP. Moreover, declining in the burning rate was observed with increase in the wool fibre weight content.

Many works have been reported regarding the application of waste silk fibre in reinforcing thermoplastic composite. Different methods of producing this type of composite are liquid molding, compression molding, and injection molding. It was observed that waste silk fibre can successfully replace glass fibre because of its higher tensile strength, good elasticity, excellent resilience in addition to its renewability and biodegradability nature. Moreover, it was recommended to be used for building structural applications such as doors and window panels, ceilings, partition boards and for automotive and railway interiors, and storage devices as low-cost material. Likewise, investigation on ability of chicken feathers (CFs) in reinforcing polylactic acid (PLA), Polybutyrate adipate terephthalate (PBAT) and a PLA/thermoplastic copolyester resin was carried out by [15]. 0% and 60% weight of waste chicken feather contents were used. The interfacial adhesion between CFs and the matrix was improved with the alkali and a plasticizer like polyethylene glycol (PEG). The resulted composite was light in weight and possessed a good thermal insulating property. It was mentioned as alternative material for some wood and plastic component in flooring and building materials. Furthermore, the empirical models for estimating the mechanical properties and morphological of recycled low-density polyethylene/snail shell bio-composites were investigated by [25]. The snail shell of different particle sizes and weight percentages were used to reinforce RLDPE, and compressive molding technique was used to prepare the composites. Then the composites were subjected to mechanical testing such as tensile, flexural and impact energy. Results obtained showed that the higher the weight percentage of fibre, the higher the properties till it reaches 15% weight of fibre. Consequently, the developed composite was recommended for fabrication of indoor and outdoor structural parts.

V. PAST WORK ON ANIMAL AND PLANT FIBRE (HYBRID) REINFORCED THERMOPLASTIC COMPOSITE

Natural keratin fibre (KF) from waste human hair and waste coconut fibre (CF) were used as fibres in fabricating, starch-polyester blend thermoplastic composites. Then the morphology, rheological and mechanical properties such as young modulus, tensile and impact strengths as well as pyrolysis, flammability and forced flaming combustion behavior of the composites were investigated. Also, to improve flame retardant behavior of the composites, ammonium polyphosphate (APP) was added. Results revealed that the KF and CF were able to increase the young modulus of the composites, but their impact and tensile strengths were reduced. Moreover, APP was able to improve the flammability behavior of the thermoplastic composites (TPCs). There was a change in charring burning behavior when the flame-retardant APP was added. CF was able to further reduce Peak heat release rate (PHRR) and total heat evolved than the KF. Lastly these wastes together with APP were proposed for sustainable retarded materials for sustainable development. Similarly, another researcher [26] selected silk as animal fibre and jute as plant fibre. both were used to reinforce polypropylene. Subsequently, compression moulding method was used to fabricate the composites, then tensile strength, impact strength, bending strength, bending modulus, and young's modulus of the composites were measured. The comparative study makes it obvious that mechanical properties of silk/PP composites are greater than those values of jute/PP composites.

VI. PAST WORK ON ANIMAL FIBRES (HYBRID) REINFORCED THERMOPLASTIC COMPOSITE

The effect of chemical treatment on the mechanical behavior of animal fibre-reinforced high-density polyethylene composites was studied by [27]. Chicken feather and cow hair fibres were animal fibres used. Two different samples were prepared. One was treated with 0.25 M NaOH, while the other was not. Then 2, 4, 6, 8 and 10 % fibre loading were done and the method employed was hot compression molding. Flexural and tensile tests were conducted on both. Results revealed that the treated cow hair and chicken feather fibre reinforced high density polyethylene composites are better in terms of best flexural properties for most fibre loading percentages compared to their untreated. However, the tensile properties of both samples were not improved. Therefore, the developed composites will be suitable where high flexural strength materials are required.

VII. CONCLUSION

This paper is an overview of animal fibre thermoplastic composite materials for engineering applications. It also compiles the available works on different animal wastes that have been used as reinforcement materials in thermoplastic composites. Likewise, it reveals some important properties of various thermoplastic matrixes or resins. Similarly, relevant data regarding the properties of these animal fibres were mentioned.

Lastly the existing areas of applications of animal fibre reinforced thermoplastic composites were pointed out.

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