Material Science Research India Vol. **4**(2), 487-492 (2007)

Feather fiber reinforced polyester composites

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(Received: November 18, 2007; Accepted: December 23, 2007)

ABSTRACT

Chicken feathers, generated in large quantities while processing chicken for meat, by and large are going waste. Added to that, the disposal of feather waste at the processing plants is posing ecological problems. The problem is more serious in India due to the prevailing marketing habits. Chicken meat is processed and sold in small and scattered shops in urban areas of India, unlike in the developed countries and the generated feather waste is dumped mostly into canals indiscriminately resulting in serious pollution. Present study is aimed at finding ways and means to use chicken feather in polymer matrix composites, replacing the existing man made fibers. Chicken feathers were collected from a local meat shop, processed to prepare chicken feather fibers (CFF) and then mixed with polyester resin for preparing the composite material. Test samples were prepared with varying fractions of feather fiber (0 - 3.0%) using hand lay-up process. An increase in elastic modulus and tensile strength of the composite over the virgin polymer was observed up to 2.0% weight fraction. Similar trend was observed in flexural tests also. SEM examination revealed proper interaction between the polymer and feather fiber. In addition, the low density of feather fiber resulted in a composite that is lighter. The lower cost combined with reasonably higher strength of CFF-Polyester composite qualify it for specific consumer applications like nonstructural auto components and coverings for domestic gadgets etc.

Key words: Chicken feather fiber, polyester matrix composites

INTRODUCTION

Chicken feather, generated in millions of tons every year, is almost going waste at present all over the world. Al so, the way feathers are generated and disposed off, generally in Asia and particularly in India is polluting urban surroundings very seriously. This is attracting many researchers to find ways and means of utilizing feathers for consumer applications. Chicken feather fiber (CFF) being fibrous by structure is suitable as reinforcement in developing composite materials. The sustained availability of CFF makes it more suitable in composites for various consumer applications where high strength is not a primary requirement. Also use of CFF in place of man made fibers makes the composites less expensive. Taking the case of India, fiber reinforced polyester composites find a number of applications in consumer products. More importantly, these products are hand made and the production units are spread across the country. While the feather generation in the developed part of the world is concentrated at meat processing plants, it is highly scattered in India due to the prevailing customs and habits. This type of scattered availability of chicken feather suits the scattered production units of fiber composites prevalent in India.

Many attempts were made to utilize the feathers which otherwise have become a burden to dispose off. One such attempt was to use feathers in animal feed but the recent findings that feather meal is a potential disease carrier forced many governments to ban the feather meal altogether[1]. Hence attempts to use feather fiber for other applications have been on the rise. Also the mandate in USA, Europe and Australia, that at least 60% of automobile interiors should be made of biodegradable materials is another encouraging factor to replace the man made fibers with natural fibers. Processed feather fibers have been found to be a better alternative to man made fibers by virtue of their bio degradability. The advantage of feather fiber is that it is available at major processing plants as well as in small retail shops in India on daily basis and not seasonally unlike other natural fibers. Hand lay-up process (popularly known as bucket and brush technique) is more popular amongst small production units in India. This paper attempts to investigate the suitability of chicken feather fiber as reinforcement in polyester matrix composites for specific consumer applications.

Feather structure:

Feather mainly consists of four components, viz.

1. quill or rachis
2. barbs
3. barbules
4. hooklets

Quill is the central shaft that holds on to the bird's body while barbs branch out from the quill. Barbules further branch out from barbs and hooklets branch out from barbules[2-3]. Fig. 1 shows the detailed structure of a feather. Though the quill fraction of the feather appears totally different from the rest three fractions, chemically all are keratin. The sequence of amino acids that forms keratin in feathers differentiates quill from barbs[4]. While quill is β-keratin (sheet), barb and barbule are α-keratin (helix). Hence the mechanical properties and physical appearance of barb and barbule are far different from that of quill. Quill portion of the feather is brittle and sheet like and hence does not qualify as fiber. Rest of the feather fractions (barb, barbule and hooklet) is soft and all fibrous. Mutual cohesion coupled with good tensile strength and high aspect ratio along with uniform diameter make CFF a suitable fiber for developing composites. About 40% of the 95 amino acids in keratin are hydrophilic and the remaining 60% are hydrophobic[5]. Some researchers claim this to be 50:50[6]. This makes feather fiber find application with both hydrophilic and hydrophobic resins.

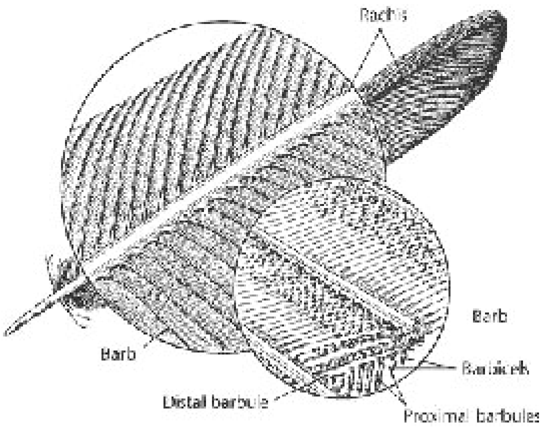


Fig. 1(a): Detailed view of a typical feather as seen through a microscope

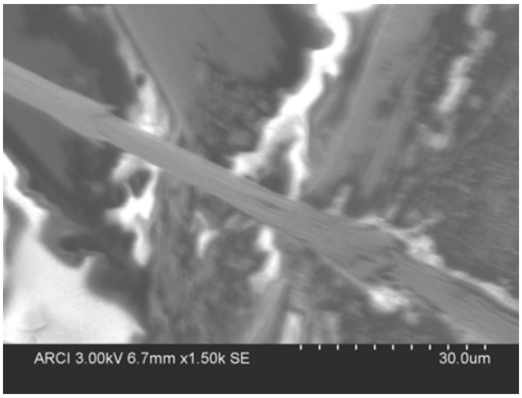


Fig. 1(b): Scanning Electron Micrograph of a barbule

Feathers have been a subject of interest since many decades and found various applications in the society[7-8]. Abundance of chicken farming for meat all over the world resulted in generation of chicken feather in huge quantities at processing plants that has become a burden to dispose off.

Chickens are grown primarily for two purposes: eggs and meat. Egg producing chickens are called layers and they live nearly for 500 days before they are culled. Meat variety chickens are called broilers and they are grown for 55 to 60 days before they are killed for meat. Naturally the feathers of layers are older, fully grown and stronger when compared to feathers of broilers which are tender and softer due to the age factor. Like all birds, chicken too have flight feathers (fully grown, longer and stiffer) as well as down feathers (shorter and softer). Another important feature of broiler chicken is that nearly 80% of the feathers are down feathers or after feathers while layers have less than 60% down feathers. Also the generation of broiler feathers is universally more when compared to layer feathers due to the short cycle time of broilers. Hence the rate of production of broiler feathers ensures a sustained supply of CFF.

For any material to qualify as a fiber, uniform diameter and high aspect ratio (50 and above) of the fiber are two important prerequisites apart from good tensile strength and mutual cohesion. Chicken feather fiber satisfies all the four requirements to a greater extent. The average diameter of barbules of chicken feather is of the order of 5 to 6 μm and the aspect ratio falls between 50 and 400[9]. Abundance in the availability of chicken feather and ease of handling qualifies CFF as a renewable alternative raw material to replace the existing sources to some extent. Over and above, CFF is non toxic and not hazardous to the worker, unlike glass fiber.

The density of chicken barb is less than half that of established man made fibers like glass fiber. Hence in applications like fillers, insulators and filters, using feather barbs make them much lighter though the weight reduction is insignificant in composites. Compared to other natural fibers like sisal, jute and coir, feather fibers have less tensile strength. Also the recovery fraction of useful fiber from feathers is much more compared to other natural fibers like banana and jute. The tensile properties of other natural fibers along with feather fibers are summarized in Table 1 for comparison.

Table 1: Comparison of tensile properties of feather fiber with other natural fibers

S. No.	Fiber	Density (kg/m^3)	Diameter (μm)	Tensile strength (MPa)	Tensile modulus (GPa)
1.	Feather fiber	780-900	5-6	130	3.0-4.5
2.	Sisal	1450	50-300	227-700	9-20
3.	Jute	145	-	533	20-22
4.	Coir	1150	100-460	108-252	4-6
5.	Banana	1350	80-250	529-759	8-20

Polyester matrix composites

The ability to be used in hand lay-up technique makes polyester a more convenient matrix material in comparison with polyethylene in the production of fiber reinforced composites. The scattered generation of chicken feather and also the scattered location of small scale production units coupled with abundance of human labor available in India makes polyester the most suitable resin for hand made composite products. Using appropriate accelerator enables polyester matrix composites set quicker.

MATERIAL AND METHODS

Barb part of the chicken feather (as reinforcement) and polyester resin (as matrix) were used to prepare the present composites. Polyester resin was ECMALON 4411 procured from ECMASS Resins Pvt. Ltd., Hyderabad. The resin has a density of 1258 kg/m^3, Young's Modulus of 630 MPa, tensile strength of 31.5 MPa and elongation at break of 5%. Chicken feathers were collected from a local meat selling shop. Feathers were plucked dry and were randomly selected for this study. However it was mostly flight feathers that were picked for separating the barbs from quill. Chicken de-feathering in most of the Asian countries is done at the selling points and so is highly decentralized. This is due to customer preferences and also due to prevailing habits. The processing plants are very few in India (with respect to its huge human and bird population) as compared to Europe, America and Australia and so it was felt that the feather collection could be done anywhere without any prejudice to the out come of the results. Separation of barb from the quill was done by shearing as the quantity required was small.

Preparation of CFF

Feathers collected at the meat selling points were dirty and exhibited oppressive odor. This could be attributed to the farming methods employed universally to grow broiler chicken. The separated barbs (fibers) were then soaked in methanol bath for 30 minutes to ensure reduction of dirt and bad odor. Then the fibers so collected were oven dried to ensure the removal of excess moisture[10]. Oven drying was limited to 15 minutes to ensure that natural physical properties of barb did not alter.

Preparation of composite samples

Dies were prepared as per ASTM D 638 for tensile sample and ASTM D 790 for flexural sample in a rubber sheet and then glued to a glazed ceramic tile. The ceramic tile helped in obtaining one of the surfaces of the test samples smooth and the thickness was under control. Polyester resin was taken in an open bowl. Catalyst and accelerator were added to the resin and the mixture was thoroughly stirred. Gel coat was applied in the die cavities with a brush till a thin layer was formed. Feather fibers were treated in resin before being placed in the die to ensure complete wetting and to avoid formation of air bubbles. The wetted barbs were laid in longitudinal alignment. The remaining depth was filled up with resin and barbs, layer by layer as it was done earlier, progressively. Top face of the mould was covered with a polythene sheet and a roller was passed along the length to drive out excess resin and also to ensure smooth surface and proper geometry of the test specimen. The preparations were left to cure completely and then were removed from the dies. The samples were made with varying weight fractions of fiber at 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0% w/w. For each weight fraction, five samples were made and the best four (physically) were chosen for testing.

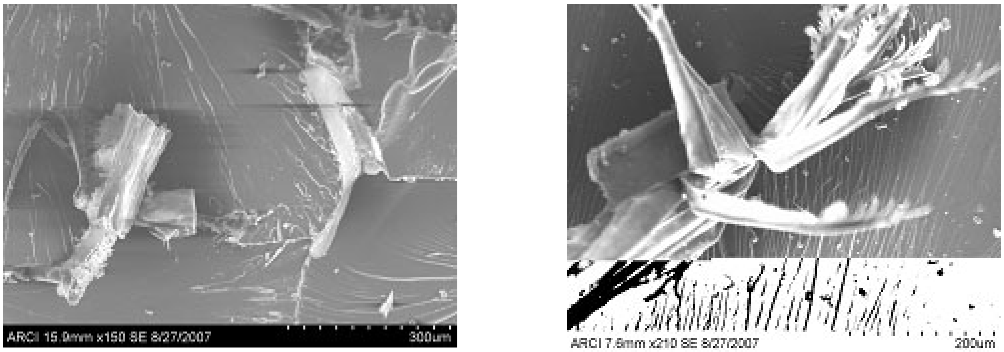
Testing

For assessing the effect of feather fiber presence in the polyester matrix composite, two primary tests were conducted, viz. test for tensile strength and test for flexural strength. To study the interaction between matrix and the reinforcement, SEM analysis was conducted on fractured surfaces of tensile test specimen.

Test for tensile strength was conducted on Tensometer model TMER 3 available at Government Polytechnic, Vijayawada, Andhra Pradesh in a conditioned atmosphere of 25°C temperature and 65% RH. For tensile strength test, the cross head speed was maintained at 5 mm/min and for flexural strength test the loading was static. Dial gauge (Mitutoyo, Japan make) of 0.01mm least count was used to measure the deflections in flexure tests. SEM analysis was taken up at ARC International, Hyderabad.

Table 2: Ultimate tensile strength and Young's modulus of the composites for various weight fractions

Weight fraction(%)	UTS (MPa)	Young's modulus (GPa)
0.0	31.04	0.53
0.5	37.28	0.63
1.0	39.24	0.72
1.5	42.20	1.03
2.0	47.10	1.07
2.5	32.56	1.02
3.0	31.90	1.01



(A) (B)

Fig. 2: a) SEM of fracture surface of 3.0% weight fraction specimen
b) SEM of fracture surface of 2.0% weight fraction specimen

RESULTS AND DISCUSSION

Table 2 shows the UTS and Young's modulus of the composite material for various weight fractions of feather fiber. The results indicate the rise of strength of the composite up to a weight fraction of 2.0% and beyond 2.0% the strength dropped. SEM analysis reveals a better interaction between the fiber and the matrix (Fig. 2). Broken fibers at the fracture surface, for 2.0% weight fraction, indicate a strong adhesion between the fiber and the resin. Pulled out fibers at the fracture surface, for 3.0% weight fraction, indicate poor adhesion between the fiber and the resin. This may be due to the presence of excessive fiber than the matrix could normally accommodate for effective adhesion. Table 3 shows flexural strength and flexural modulus of the composite material for various weight fractions of fiber. The flexural strength increased up to 2.0% substantiating the tension test results.

Table 3: Flexural strength and flexural modulus of the composites for various weight fractions

Weight Fraction(%)	Flexural Strength(MPa)	Flexural Modulus(GPa)
0.0	67.88	2.23
0.5	69.30	2.45
1.0	77.58	2.67
1.5	85.59	2.71
2.0	96.62	2.86
2.5	82.47	2.65
3.0	71.16	2.53

Conclusions

The inclusion of feather fibers as reinforcement in polyester matrix has increased the tensile strength of the composite compared to the virgin polyester. However, the tensile strength reached a peak value for a weight fraction of 2.0% and started dropping for higher weight fraction beyond 2.0%. Similar behavior of the composite was observed in flexure test also. The specimen became stiffer in bending at a weight fraction of 2.0%. SEM analysis revealed better interaction between the fiber and matrix for weight fraction of 2.0% than at higher fractions. Further research in the direction of developing a suitable coupling agent and non-woven CFF mats may qualify feather fiber for various consumer product applications. Though the strength of CFF-polyester composites is relatively less compared to glass fiber reinforced composites, they may find application in products where strength is not the primary criterion. Cost advantage, sustained availability, bio-degradability and non-hazardous nature qualify CFF as a better alternative to man made fibers.

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