Physical and Mechanical Characteristics of Feather Fiber based Filled Circular Tube

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***Abstract*:- Application of feather fibers in engineering applications is on growing trend and feather fibers are used in composite panels and thermal insulations. The intent of this paper aimed to study physical and mechanical properties of feather fiber based filled tube which is also known as FETUBE. Physical and mechanical properties are crucial to evaluate the industrial application of FETUBE. Experimental tests were conducted on FETUBE to evaluate tensile and compressive strength. Apart from tensile and compressive strength tests, various other important test such as bending strength, shear strength, torsion strength, and impact strength were conducted on FETUBE. The toughness of tube and modulus of elasticity were evaluated as a function of percentage of moisture content. Test results were reviewed and conclusions were drawn based on the exponential data. Experimental tests were conducted considering the average diameter of the FETUBE.**

Keywords: Natural fibers, Feather Fiber based filled tube, FETUBE, physical and mechanical properties of feather fibers.

I. INTRODUCTION

Natural fibers have inherent superiority over conventional synthetic fiber materials, such as weight to strength ratio, cost advantages, raw material availability, carbon foot print and degradability. Poultry feather fibers (FFs) are gaining popularity in industrial applications and in the field of composite applications. Fibers play vital role in matrix based composites and synthetic fibers are being used extensively in the composite panel manufacturing. Environmental issues and dependency on petroleum based products made the composite industry to look for better options to use natural fibers and ecofriendly polymers from renewable resources.

Natural fibers can be broadly classified as cellulose based and protein based fibers. Animal based fibers are protein based fibers. Over 3.8 million metric tons of poultry meat was produced across India in 2019[1]. It was estimated that 6% of a bird’s body weight is feathers [3], the amount of feathers coming out of Indian poultry facility is around is about 0.32 million metric tons. Usually poultry feathers are treated as waste, and disposed in open ground or burned. Disposal of the poultry waste is very expensive and produces bad odder and ill effects on surrounding environment [4]. The use of poultry feather fiber as reinforcement in composites is an innovative solution for poultry feather waste disposition and also provides additional revenue for the poultry industry. Bird feathers are considered as the most conglomerate integumentary appendages in vertebrates [5]. Feather fibers are made of keratin proteins ([90 wt %) [6] and the amino acid contents were studied by Graham [7], Schmidt [8], and Franer et al. [9].

Poultry feathers have two important parts namely feather fiber and quill and they are equal in weight percentage contribution. Poultry feathers inclusive of quill and feather fibers are made of protein known as hydrophobic keratin, which has strength comparable to nylon and cross-sectional diameter smaller than wood fiber [10]. Feather fiber has high aspect ratio than the quill and very good durability. Feathers extracted and collected from poultry facility cannot be made into new materials and needs cleaning process. The central part of feather known as core is also called as feather quill, is a stiff part and must be separated from the barbs. Barbs can be used as reinforcement material for composites and barbs in powder format can be used as fillers in matrix materials. Feather barbs are comparatively shorter in length and cannot be spun into thread and cannot be woven into cloth due to surface property of the feather fibers, but they can be added with man-made synthetic materials to form mat or slab where fibers are randomly oriented. The length of the barbs purely depends on the position along the rachis. The barbs on the base of the rachis are longer when compared to the fibers at the tip. Feather fiber property depends upon the percentage of keratin, which varies with ecological conditions of poultry facility [11-15].

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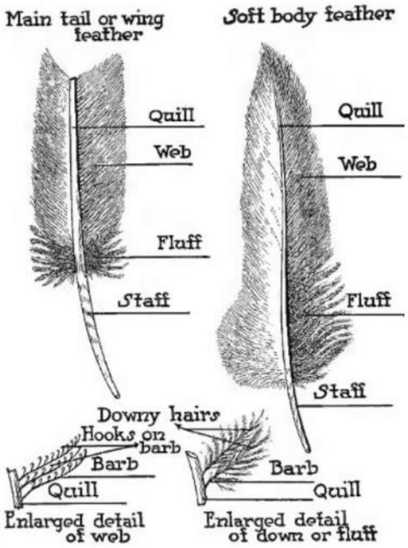

Figure.1 Details of Poultry feathers [18]

The average length of poultry feathers are roughly around 135mm. The density of poultry feathers was found to be around 0.8 g/cm3 and know to be lighter material [16]. Feather fiber diameters were found to be in the range of 5μm and lengths of 3-13 mm. These values correspond to aspect ratios of 400-2200. Mature and well grown 5lb or 2.25kg broiler chicken's feathers weigh about 74 grams or 2.6 ounces, or 3.3 percent of its body weight. Since that chicken has some 9,000 feathers, each one weighs about 0.0082 grams [17]. Some of the important tests and results on poultry feathers are tabulated in Table.1, Table.2 and Table.3

Table.1 Tensile Test details of Feather Quill

Sample	Breaking load N	Deformation at Break mm	Tensile Deformation at break mm	Average strain	Average stress N/mm2	Young"s modules E Mpa
1	34.07	0.37	0.3759	0.035	6.00	173
2	36.81	0.897	0.896	0.045	6.55	147
3	35.02	0.394	0.395	0.032	6.13	189
4	36.11	0.473	0.47	0.032	6.13	189
5	36.17	0.341	0.34	0.016	5.87	364
Max.	**36.81**	**0.897**	**0.896**	0.045	6.55	364
Min.	**35.01**	**0.341**	**0.34**	0.016	5.87	173

Table.2 Fluid Resistance test of the Quill and Barbs

SL.No	Test medium	Quill after 24hrs drying	Barbs after 24hts drying
1	Cold Water	1.1% Weight loss	1.52% weight loss
2	Hot Water	1.5 %Weight loss	2.56% weight loss
3	With 2% Na_2CO_3 (Washing Soda)	1.64% Weight loss	18.877 % Weight loss
4	With 1% Hcl (Hydrochloric acid)	5.65% weight loss	4.494 % Weight loss
5	With 5% NaOH (Sodium Hydroxide)	Completely dissolved	9.14% Weight loss

Table.3 Flammability Response of Feathers

Sl.No	Description	Burning Behaviour			Residue	Odour
		When approached Flame	When in the Flame	Removed from the Flame		
1	Quill	Fuses	Fuses and Burns	Supports combustion for a long time	Easily crushable. Black Soft ash	Burning rubber
2	Barbs	Fuses	Fuses and burns	Supports combustion for a short time	Completely Fuses	Burning Hair

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II. POULTRY FEATHER FIBER BASED FILLED TUBE- FETUBE

FETUBE is a newly developed proprietary material made from bundles of poultry feathers in a particular pattern. Clean and processed loose bundled feathers with or without quill reinforcement, wrapped in thin layer cotton based lenin was moulded in split pipe mold to form a filled tube. Dilute SR998 rubber based resin was used during the bundling process of feather fibers. FETUBE is vacuum cured and temperature cured as per the form fit functional requirements. Diameter of the tube ranges from 4mm to 12mm and tubes of diameter less than 6mm are without quill reinforcement and tubes with diameter greater than 6mm, comes with quill reinforcement of diameter 3mm to 4mm. The wrapping of thin layer of cotton based lenin acts like braiding and holds loose feather fibers intact. The exterior surface of the tube is provided with thin coating of SR998 to prevent moisture entrapment and activated surface for future fabrication. Visually, FETUBE resembles as dried maize stalk with good bending property.

Figure-2 Feather Fiber based filled tube - FETUBE

Figure-3 Failure of feather fiber filled tube FETUBE after Tensile Test

Based on preliminary testing, the axial tensile strength of diameter ø12mm FETUBE was 53.96MPa. The average secant modulus of elasticity is 28.06GPa and the average boundary deformation is equal to 0.98%. The destruction of the rods took place by cracking of the subsequent fibers. The detachment of the braiding from the bar core was noticeable. The destruction was accompanied by a decrease of strength. The intent of this paper is to study the behavior of FETUBE in detail so that FETUBE can be used in generic and industrial applications

III. PHYSICAL CHARACTERISTICS OF FEATHER FIBER BASED TUBE - FETUBE

FETUBE samples are available in running length and maximum length of the FETUBE is 1.25m. FETUBES are available in standard cross sectional diameter starting from 6mm to 12mm.The test samples of FETUBEs were prepared as pert test requirements. The important physical parameter for specific tests are tabulated in Table.4. Test samples were cut from the standard length tubes and were stored in oven maintained at 27ºC with humidity 50%. 10 specimens were prepared for each specific type of test.

Table.4 FETUBE – Test Specimen Geometry information

Physical Property	**FETUBE**	
	Range	**Average**
Tube length, cm	140 -150	146.09
	298-305	302
	430 - 440	437
Tube diameter, (6)mm	5.2 – 6.1	5.91
Tube diameter, (8)mm	7.9 -8.2	8.01
Tube diameter, (12)mm	11.4-12.2	12.04
Mass of one 6mm Dia Tube, (g)	6.8 – 7.3	7
Mass of one 8mm Dia Tube, (g)	7.9 - 8.6	8.4
Mass of one 12mm Dia Tube, (g)	11.92 – 12.3	10.11

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The properties which influence the physical behavior of the feather fiber tube FETUBE are shear, compression and bending characteristics. Table. 5 tabulates the details of important tests for FETUBE.

Table.5 Important properties for FETUBE

Test Type	Parameters	formula	Description
Shear Test	Maximum shear strength	$\sigma_s = F_{max} / A$	σ_s are the maximum shear strength in (MPa) F_{max} is the maximum shear force in (N) A is the crosssectional area of stalk at the plane of shear in (mm^2)
Compression Test	Modulus of elasticity (compression)	$\sigma_c = [(Fc / A) / (\Delta L / d)]$	σ_c is the modulus of elasticity in compression in (N/mm^2) Fc is the compressive force in (N) ΔL is the transverse deformation due to compressive force in (mm) d is the diameter of the stalk at the point of compression in (mm)
Bending Test	Beam failure stress Modulus of elasticity(bending) Bending energy	$\sigma b = My / I$ $M = F_b \times L$	M is the maximum bending moment at which thetube fails in (Nmm) y is the distance of outermost fibre from the neutral axis in (mm) I is the second moment of area of the stem cross-section in (mm^4) F_b is the maximum bending force at which the tube fails in (N) L is the length of lever arm of the bending force in (mm).

IV. MATERIAL AND METHODS

The test samples were stored in oven to eliminate the moisture entrapment. The oven was maintained at 30ºC and at 50% humidity. Universal testing machine (UTM) maintained at standard laboratory condition was used to measure the mechanical properties (tensile strength and compressive strength at vertical plane) for FETUBE,. The machine as shown in Fig. (1). Test sample dimensions are tabulated in Table.6.

Figure.4 Standard Universal Testing Machine

Table.6. Geometrical Dimension of Test Samples

Sl.No	Test Type	Sample Length	Sample Diameter
1	Shear strength.	30mm	6, 8 and 12mm
2	Compressive strength.	25mm	6, 8 and 12mm
3	Tensile strength.	300mm	6, 8 and 12mm
4	Bending movement.	430mm	6, 8 and 12mm
5	Impact test	80mm	6, 8 and 12mm
6	Torsion test	350mm	6, 8 and 12mm
7	Moisture content (M.C)	300mm	6, 8 and 12mm

4.1 Shear strength Test on FETUBE

The shear behavior of FETUBE was determined experimentally by shear strength test and the maximum shear stress σs are expressed by the equation σs = Fmax / A. Shear strength test needs a separate pre-fabricated fixture which will be fixed rigidly to the base plate of UTM. FETUBE can be tested single and double shear strength test and is illustrated in Figure.5. The geometry of the test specimen is tabulated in Table.6. The conditioned FETUBE sample was held on the fixture with the help of U-clamps at both ends of the test specimens. During the down ward movement of the crosshead, the chisel cut the specimen by shear and passed through the slots provided in the fixture below the specimen. The force required for shearing the stalk was recorded. The maximum shear strength was calculated using equation σs = Fmax / A. The shear test was conducted for different type of FETUBE which are with and without quill reinforment.

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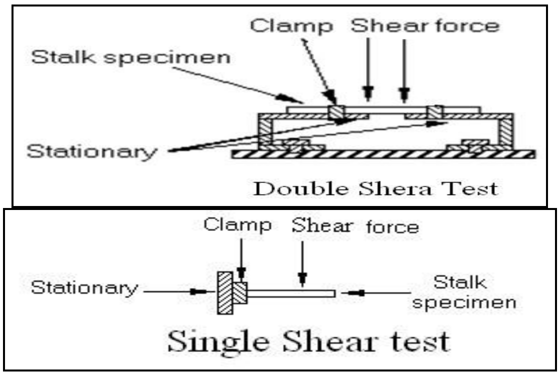

Figure. 5 Shearing testing methodology for FETUBE

Table.7 Double Shear Testing results of FETUBE

Sample C/S (Dia in mm)	Average Diameter (mm)	Area (mm^2)	Peak load (KN)	Peak load (N)	Shear strength (N/mm^2)
12mm Dia FETUBE	11.97	112.48	5.5	5500	48.90
	12.03	113.61	5.2	5200	45.77
	12.07	114.36	5.8	5800	50.72
8mm Dia FETUBE	8.1	51.50	4.1	4100	79.61
	8.03	50.62	3.96	3960	78.23
	7.9	48.99	3.91	3910	79.81
6mm Dia FETUBE	5.93	27.60	3.11	3110	112.66
	5.99	28.17	3.07	3070	109.00
	6.1	29.21	3.21	3210	109.89

Table.8 Single Shear Testing results of FETUBE

Sample C/S (Dia in mm)	Average Diameter (mm)	Area (mm^2)	Peak load (KN)	Peak load (N)	Shear strength (N/mm^2)
12mm Dia FETUBE	11.9	111.16	5.7	5700	51.28
	12.01	113.23	5.4	5400	47.69
	12	113.04	6	6000	53.08
8mm Dia FETUBE	8.02	50.49	4.7	4700	93.08
	8.07	51.12	4.5	4500	88.02
	7.95	49.61	4.11	4110	82.84
6mm Dia FETUBE	5.97	27.98	3.71	3710	132.60
	6.04	28.64	3.57	3570	124.66
	6.01	28.35	3.31	3310	116.74

4.2 Compression Test on FETUBE

The compression behavior of the FETUBE was determined by compression test and the modulus of elasticity in compression was calculated by the following equation $\sigma_c = [(Fc / A) / (\Delta L / d)]$. The conditioned specimen was placed on the base plate of the UTM perpendicularly. The geometry of the sample is tabulated in Table.6. The compressive force on the FETUBE sample was applied by a flat heads as shown in Figure. 6. During the test, the cross-head was moved down at 25 cm/s speed deforming the sample until failure of the sample and the modulus of elasticity in compression was calculated using above equation.

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Vol. 8 Issue 12, December-2019

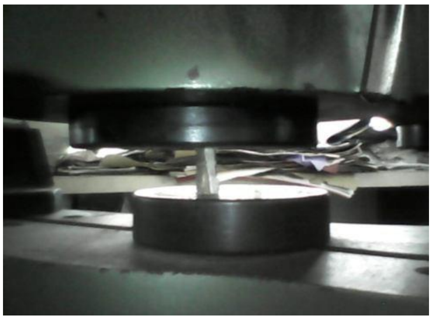

Figure. 6 Compression test on FETUBE

Table.9 Compression Testing results of FETUBE

Sample description	Diameter of sample	Sample Length (mm)	Area (mm^2)	Compression force Fc(KN)	Compression Force Fc(N)	Change in length of sample (mm)	Compressive Strength (N/mm^2)
12mm FETUBE	11.9	25	111.16	2.88	2880	20.12	63.18
	12.01	25	113.23	2.51	2510	19.23	46.14
	12	25	113.04	2.12	2120	19.33	39.69
8mm FETUBE	8.02	25	50.49	1.5	1500	19.41	42.62
	8.07	25	51.12	1.49	1490	18.75	37.63
	7.95	25	49.61	1.29	1290	15.65	22.11
6mm FETUBE	5.97	25	27.98	0.75	750	14.78	15.66
	6.04	25	28.64	0.71	710	14.52	14.29
	6.01	25	28.35	0.62	620	13.88	11.82

4.3 Tensile strength Test on FETUBE.

Tensile strength tests were performed by fixing the test specimens in between the parallel clamps on top and bottom side of the UTM. The geometry of the test specimen is tabulated in Table.6. The test specimen's axis is placed perpendicular to the axis of the clamps. Force was applied to the sample by the force transducer to the moveable cross-head. The cross-head speed was maintained at 25 cm/s and loading was applied till the failure of the test specimen. A digital data acquisition system showed the variations in the force acting on the test specimen and the deformation at which FETUBE failed was recorded. The mechanical properties of test specimen like modulus of elasticity, toughness and tensile strength were calculated.

(a) (b)

Figure. 7 Tensile Test on FETUBE

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Table.10 Tensile Testing results of FETUBE

Sample description	Diameter of sample	Sample Length (mm)	Area (mm^2)	Tensile force Fc(KN)	Tensile Force Fc(N)	Change in length of sample (mm)	TensileStrength (N/mm^2)
12mm FETUBE	11.9	300	111.16	2.01	2010	304.2	51.23
	12.01	300	113.23	2.03	2030	305.11	42.14
	12	300	113.04	2.11	2110	303.2	70.00
8mm FETUBE	8.02	300	50.49	1.3	1300	308.1	25.49
	8.07	300	51.12	1.35	1350	309.7	21.97
	7.95	300	49.61	1.17	1170	310.3	18.20
6mm FETUBE	5.97	300	27.98	0.81	810	314.1	12.26
	6.04	300	28.64	0.71	710	312.01	12.47
	6.01	300	28.35	0.74	740	315.3	10.25

4.4 Bending Test on FETUBE

Bending behavior is very important property of the tube and the maximum bending moment was calculated by equation $\sigma_b = M_y / I$ and $M = F_b \times L$(refer Table.5). The geometry of the test sample is tabulated in Table.6. The bending property of the FETUBE was determined by simply supported teat and the test specimen axis is placed perpendicular to the plunger axis. Both end of the FETUBE specimen was fixed rigidly to the fixture with the help of a screw clamp with two inner semi-circular rims. The vertical force was applied by the chisel heads at the middle of the mounted specimen at a distance of 90 mm from the fixed point as shown in Figure. 8. Test was conducted till the failure of the test specimen.

(a) (b) (c)

Figure. 8 Bending Test on FETUBE

Table.11 Bending Testing results of FETUBE

Sample description	Diameter of sample	Compression force Fc (N)
12mm FETUBE	11.9	2021
	12.01	1997
	12	1943
8mm FETUBE	8.02	1140
	8.07	1087
	7.95	1051
6mm FETUBE	5.97	981
	6.04	583
	6.01	554

4.5 Impact Test on FETUBE

The impact teat on FETUBE was performed for determining the energy required to shear the sample in transverse as well as along the axis. The impact test can be done in two types but Charpy impact test was performed on FETUBE. The test specimen required for Charpy impact test should be of length **55 mm** and was placed in horizontal against the loading RAM. Load is to be released from 135^0 by using "V" notch for shearing as shown in the figure. 9.

Figure. 9 Impact Test on FETUBE

Table.12 Impact Testing results of FETUBE

Sample description	Diameter of sample	Energy in Joule
12mm FETUBE	11.9	473
	12.01	447
	12	433
8mm FETUBE	8.02	290
	8.07	270
	7.95	267
6mm FETUBE	5.97	107
	6.04	97
	6.01	86

4.6Torsion Test on FETUBE

The Torsion test on FETUBE was executed to determining the torque required to shear the test specimen. Test specimen required for torsion teat should be of length 350 mm and it should be clamp horizontally in the jaws provided on the testing machine as shown in figure. 10.

(a) (b)

Figure.10 Torsion Testing on FETUBE

Table.13 Torsion Testing results of FETUBE

Sample description	Diameter of sample	Energy in Joule
12mm FETUBE	11.9	98.75
	12.01	94.5
	12	92.4
8mm FETUBE	8.02	43.3
	8.07	39.29
	7.95	38.75
6mm FETUBE	5.97	23.25
	6.04	21.45
	6.01	19.875

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Vol. 8 Issue 12, December-2019

4.7 Moisture Content in FETUBE

FETUBE test specimens were oven dried at 105° C for 24 h by using electrical oven as shown in the below figure.11. The test specimens were weighted before and after drying and the moisture content was determined by using the equation,

Moisture Content = (SB – SA) / SB x 100

Where:
- *SB* = Sample mass before drying
- SA = Sample mass after drying

- **FETUBE with cross sectional dia 12 mm**

Sample mass before drying = 21.56 g
Sample mass after drying = 18.11 g
Moisture content = (21.56 – 18.11)/21.56 x 100
= 16.00 % (WB)

(a) (b) (c)

Figure. 11 Electric Oven setup and Moisture Test for FETUBE

- **FETUBE with cross-sectional dia 8 mm**

Sample mass before drying = 16.59 g
Sample mass after drying = 14.23 g
Moisture content = (16.59 – 14.23) /16.59 x 100
= 14.22 % (WB)

- **FETUBE with cross-sectional dia 6 mm**

Sample mass before drying = 13.25 g
Sample mass after drying = 11.98 g
Moisture content = (13.25 – 11.98) /13.25 x 100
= 9.58 % (WB)

V. CONCLUSION

Poultry feather fiber based filled circular tube also known as FETUBE was tested to determine and review physical and mechanical properties. FETUBE is available in running lengths up to 1.25m. The FETUBE diameter ranges from 4mm to 12mm with or without quill reinforcement. FETUBE will have quill reinforcement at the center and quill reinforcement is available only with FETUBE of diameter greater than 8mm. Various tests were performed on FETUBE like Compression Test, Tensile Test, Shear Test (Single and Double Shear), Torsion Test, Impact test and Moisture content tests. Similar tests were conducted on conditioned Maize stalk of approximate diameter 12 to 17mm. Test results of FETUBE was compared with the test results of Maize stalk and tabulated in Table.14.

International Journal of Engineering Research & Technology (IJERT)
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Vol. 8 Issue 12, December-2019

Table. 14 Test result summary

	Maize Stalk	FETUBE (12mm)
Double Shear strength (N/mm^2)	28.52	50.72
Single Shear strength (N/mm^2)	29.77	51.28
Compres sive strength (N/mm^2)	7.54	63.18
Tensile strength (N/mm^2)	40.2	51.23
Bending Compression force Fc (N)	1620	2021
Impact Energy (Joule)	656.4 6	473
Torque in N.m	108.7 5	98.75
Moisture content	18.00%	16%

Detailed review of the test results shows that the superior property of the feather fiber based filled circular tube against the agriculture based byproduct namely maize stalk. Maize stalks are used in industrial products like “Corn Board”, a maize stalk based composite panels and other civil building materials. Thus it is evident from the test results that feather fiber based tube can be used as reinforcements in composite panels and also in generic commercial applications. It is also advantageous to use feather fiber based tubes in composites as reinforcement, due to the fact that feathers and father based tubes have fire retarding characteristics and resistance to bacterial or fungal growth.

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