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Cotton Stalks Fiber-Reinforced Polypropylene Composites: Comparison of Experimental Data and Calculated Tensile Strength and Elastic Modulus

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***Abstract:* Cotton Stalks fibers(CS) were used for the reinforcement of a polypropylene (pp) matrix. Composites consisting of polypropylene reinforced with different CS content were prepared by melt-mixing method. Prepared samples of the composites were tested for tensile and elastic modulus. A comparison between theoretical and experimental results was made. The dependence of the tensile strength and elastic modulus on the fiber amount was proved experimentally. For the future work compositions having fiber fraction more than 25% should be used to validate the trend attained by this work**

Key Words: **mechanical properties; fibers reinforcement; polypropylene; composites, cotton stalks.**

I. INTRODUCTION

The idea of using cellulose fibers as reinforcement in composite materials is not a new or recent one. Man had used this idea for a long time, since the beginning of our civilization when grass and straw were used to reinforce mud bricks. In the past, composites, such as coconut fiber/natural rubber latex, was extensively used by the automotive industry. However, during the seventies and eighties, cellulose fibers were gradually substituted by newly developed synthetic fibers because of better performance. Since then, the use of cellulose fibers has been limited to the production of rope, string, clothing, carpets and other decorative products. Over the past few years, there has been a renewed interest in using these fibers as reinforcement materials to some extent in the plastics and Polymers industry due to the increasing cost of plastics, and also because of the environmental aspects of using renewable and biodegradable materials.

Since natural fibers are strong, light in weight, abundant, nonabrasive, nonhazardous, and inexpensive, they can serve as an excellent reinforcing agent for plastics.[3,4]

Over the past decade, cellulosic fillers of a fibrous nature have been of great interest as they would give composites with improved mechanical properties compared to those containing non fibrous fillers.[1]

Among the various natural fibers, Cotton Stalks fibers possess a moderately high specific strength and stiffness and can be used as a reinforcing material in polymeric resin matrices to make useful structural composite materials.

Cotton stalk, *Gossypium hirsutum*, is a lignocellulosic material abundantly cultivated in Sudan and considerably always unutilized recourses.

Polypropylene (PP), on the other hand has been widely used in everyday products, packaging materials, household appliances, automobile industry, building operations, and other industries due to its excellent performance.[2] meanwhile, its consumption maintains strong economic growth momentum on a global basis. With the exhaustion of petroleum resources, PP industry using petroleum products as raw materials is faced with increasing cost pressures. The key to solving this problem is to use low-cost filler for PP.

The present work aimed to evaluate the mechanical properties of the cotton stalks reinforced polypropylene composites and compare its theoretical data to the experimental ones.

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II. MATERIALS AND METHODS

A. Materials

Gossypium hirsutum, cotton stalks (CS) used in this work was supplied from Barakat area in Gezira scheme (Central Sudan). Isotactic PP used in this work were Supplied by Khartoum Petrochemical Company (KPC, Sudan), in powder form. The physical and mechanical properties of PP and CS fiber are given in Table I.

Property	Polypropylene	Cotton Stalks
Density g·cm^{-3}	0.914	1.40
Tensile Strength MPa	27.5	81.9
Tensile Modulus GPa	1.39	5.35
Flexural Strength MPa	28.7	113.9
Flexural Modulus MPa	1.39	5.45
Izod Impact Resistance	20 J/m	25.1
Heat Deflection Temperature	71°C	NA
Melting Point	230°C	NA
Melt Flow Index (MFI)	30g/10 min	NA

Table 1: physical and Mechanical properties of the composite constituents

B. Preparation of the materials

The cellulose fibers were isolated using the method described by Ibrahim et al [5] .The fibers were washed thoroughly with water and dried in an air oven at 80°C for 6 h, before being chopped into the desired lengths ranging from 1 to 30 mm for preparation of the composites.

C. Compounding of the composite

The PP–CS composites were prepared by melt mixing in which, the CS fiber was added to a melt of PP and mixing was performed in a Haake Rheocord mixer. To optimize the mixing parameters, composites were prepared by varying the mixing time, rotor speed, and chamber temperature. The mix was taken out from the mixer while hot and then subjected to sheeting using a two roll mill. Rectangular specimens measuring 150 X 150 X 2.5 mm were prepared by compression molding at a pressure of about 8 MPa and at a temperature of 170°C. They were then cut into specimens of size 120 X 12 X 2.5 mm.

The specimens of oriented fiber composites were prepared by a combination of injection-molding and compression- molding techniques.

The composite was first processed to obtain 4-mm thick cylindrical rods using an injection-molding machine (Figure 1). Rectangular specimens measuring 120 X 26.5 X 2.5 mm were prepared by aligning the extrudate (120-mm long and 4-mm diameter) in a leaky mold and then compression molding at a pressure of about 8 MPa and at a temperature of 180 5°C. The specimens were removed after cooling the mold below 50°C.

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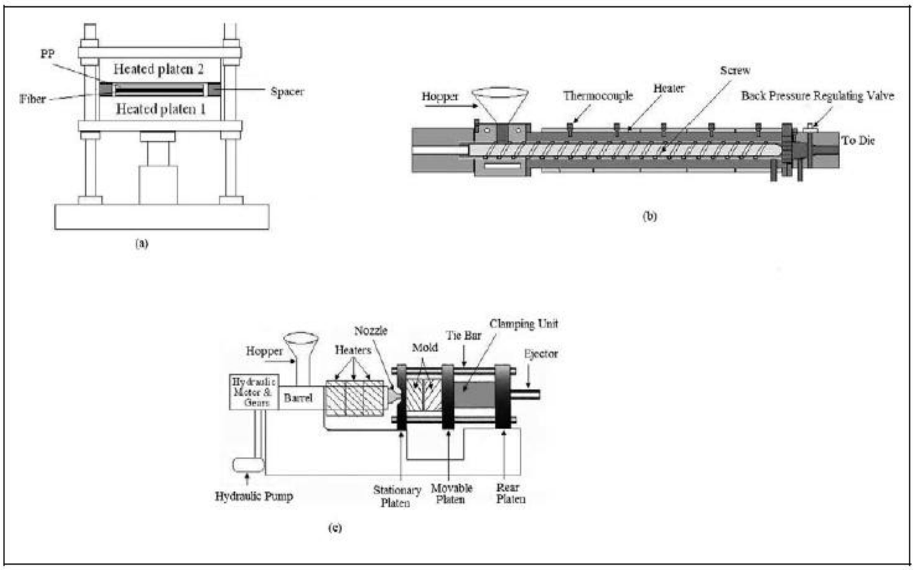

Fig (1): (a) Compression, (b) Extrusion and (c) Injection Molding Machines[6,7,8]

D. Testing methods
Tensile strength tests were carried out as per ASTM D 638 on universal testing machine UTM (Lloyds, LR 100 K).

E. Specimens compositions
Five different compositions of the composite according to the fraction volume of the fiber in addition to the blank sample were prepared as in table 2:

Composition %	
PP	CS
100	00
95	05
90	10
85	15
80	20
75	25

Table 2: Test Samples compositions

III. RESULTS AND DISCUSSION

A. Theoretical Considerations
Mechanical properties of FRP
For fiber-reinforced composites, mechanical properties are of major concern as reinforcement affects the mechanical properties of FRP. tensile strength, elasticity, impact strength and hardness are some mechanical properties that are considered significantly for a FRP. These mechanical properties of FRP generally depend on the properties of fibers incorporated in the composite.

Consider a simple unidirectional composite lamina reinforced with continuous fibers which are initially well-bonded to the matrix so that under load fibers and matrix deform together (Figure 2).

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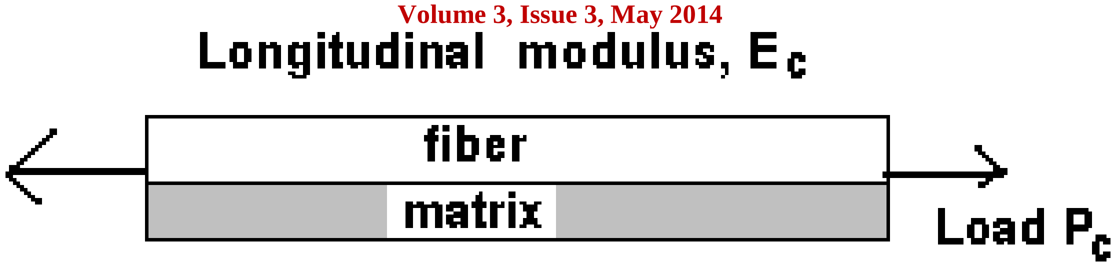

Fig (2): Longitudinal Elastic Modulus for Fiber Reinforced Matrix

Elastic Modulus (Young Modulus) or stiffness can be estimated for the composite materials using **Voigt estimate** (familiarly known as ***rule of mixtures***) to give:

$$E_c = E_f V_f + E_m(1 - V_f)$$

where E_m and E_f , the elastic moduli of the matrix and reinforcement fiber respectively, and the sum $V_f + V_m = 1$.

However, in the transverse direction the elastic modulus of the composite according to **Reuss estimate**, sometimes called the ***inverse rule of mixtures*** as follows:

$$E_t = \frac{E_f E_m}{E_m V_f + E_f(1 - V_f)}$$

Strength is more difficult to predict than elastic properties because it depends on the mechanisms of damage accumulation and failure as well as on the properties of the constituents, and the failure behavior of fiber composites is often complex.

The tensile strength of the composite can easily estimated using the fiber fraction and the constituents' stresses as the load is shared between them and, the stress on the composite, (σ)c, can be written as:

$$(\sigma)_c = (\sigma)_f V_f + (\sigma)_m (1 - V_f)$$

Where $(\sigma)_f$ and $(\sigma)_m$ are the stress levels in fibers and matrix, and are equal to E_f ε and E_m ε, respectively, where ε is the composite strain. V_f is the fractional volume of the fibers in the composite.

The fiber volume fraction, V_f, is the critical material parameter for most purposes, this clearly illustrated in (figure 3):

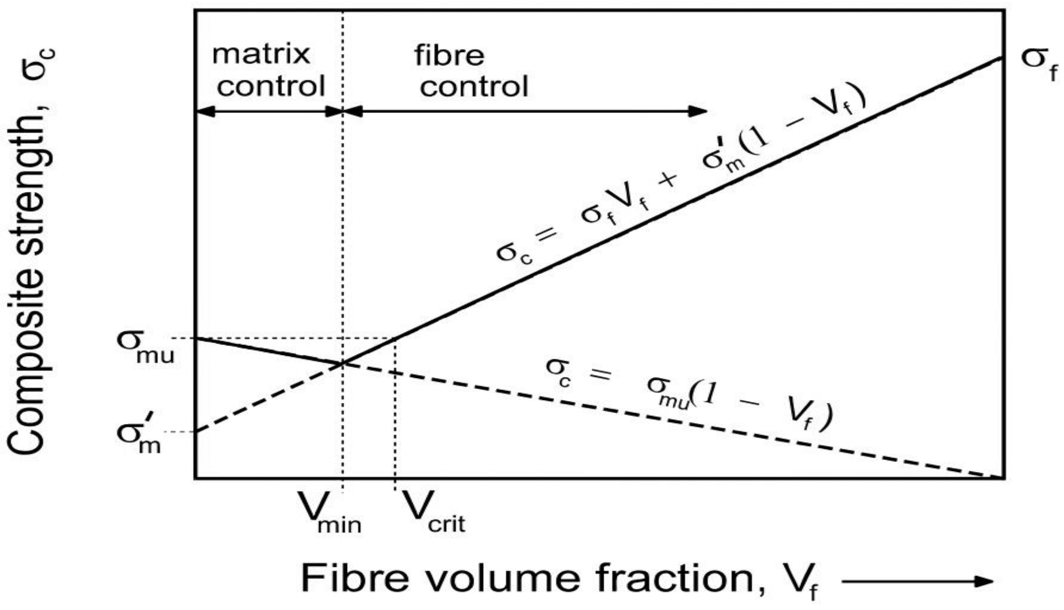

Fig (3): Effect of Fiber Volume Fraction on the overall Composite Strength [9]

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B. Calculated Mechanical Properties

The tensile strength and Young's modulus for the six prepared samples were calculated according to the given values in table (1) and then tabulated in table 4 together with the resulted experimental data and illustrated in Figures(4 to 9).

Composition %		Fiber Fractional Volume	Calculated Values		Experimental Values	
PP	CS	V_f	Tensile Strength σ_c MPa	Elastic Modulus E_c GPa	Tensile Strength σ_c MPa	Elastic Modulus E_c GPa
100	00	0	27.5	1.39	22.23	1.31
95	05	0.05	30.22	1.59	28.40	1.43
90	10	0.10	32.94	1.79	33.32	1.62
85	15	0.15	35.66	1.98	33.92	1.78
80	20	0.20	38.38	2.18	35.40	1.99
75	25	0.25	41.10	2.38	38.00	2.17

Table 4: Calculated and Experimental Strength and Modulus for different PP-CS composite compositions

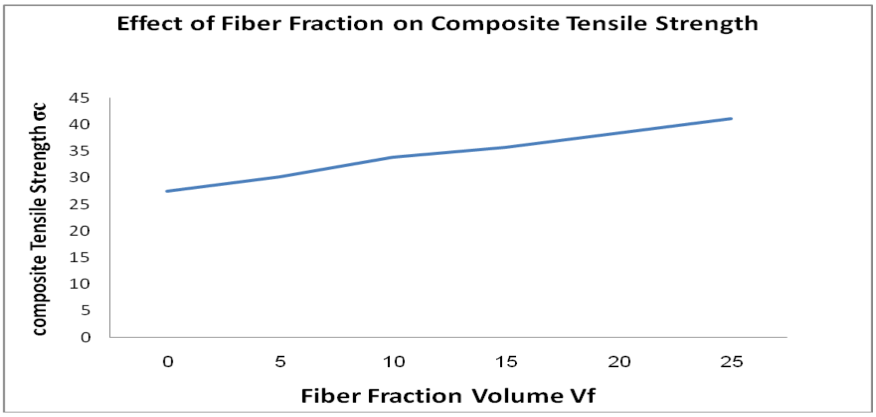

Fig 4: Calculated Fiber Fraction Volume V_f versus Tensile Strength σ_c

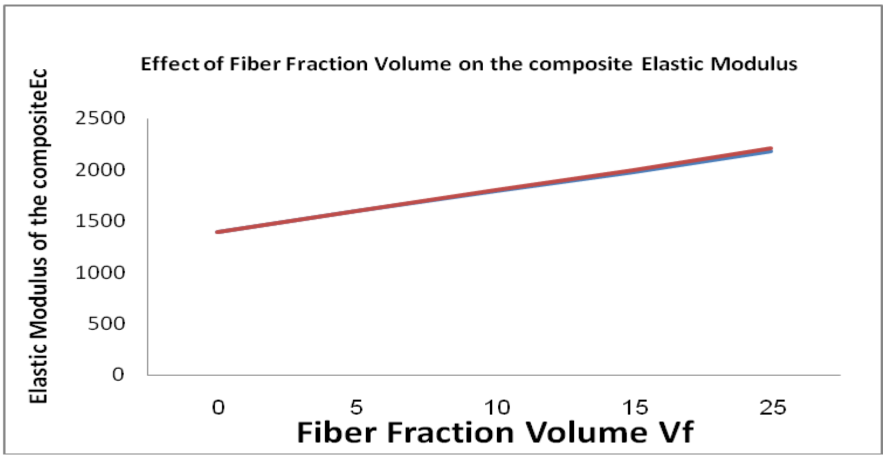

Fig 5: Calculated Fiber Fraction Volume V_f versus Elastic Modulus E_c

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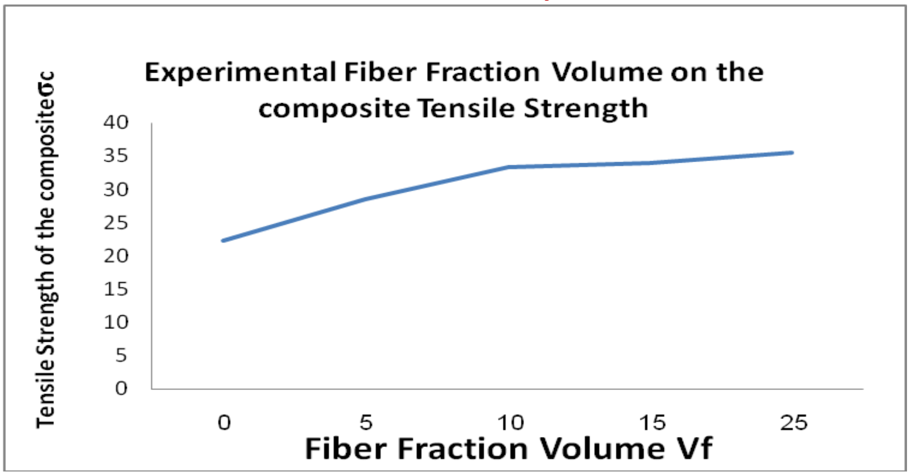

Fig 6: Experimental Fiber Fraction Volume V_f versus Tensile Strength σ_c

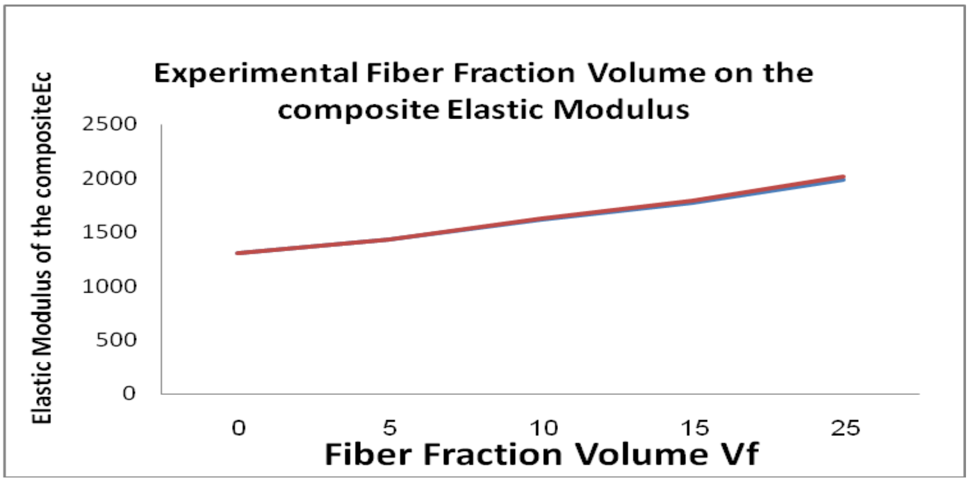

Fig 7: Experimental Fiber Fraction Volume V_f versus Elastic Modulus E_c

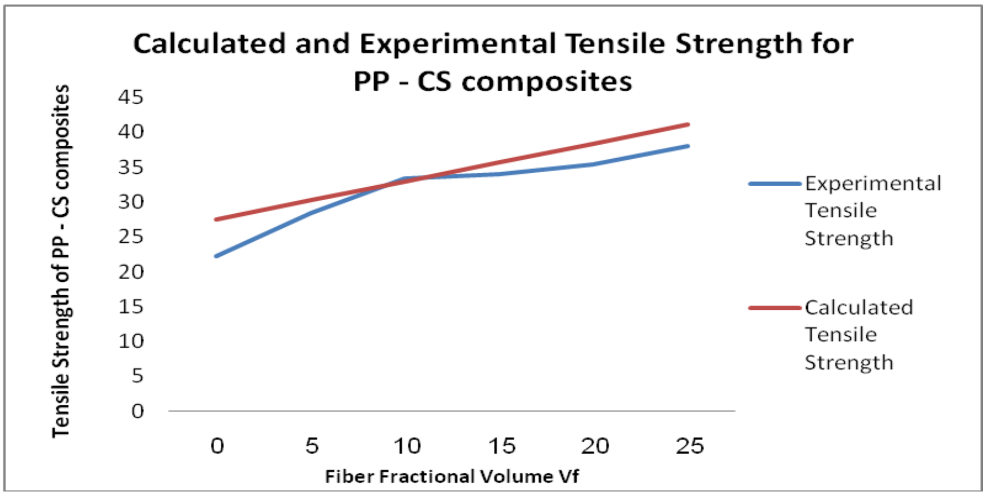

Fig 8: Experimental and Calculated Tensile Strength for PP –CS Composites

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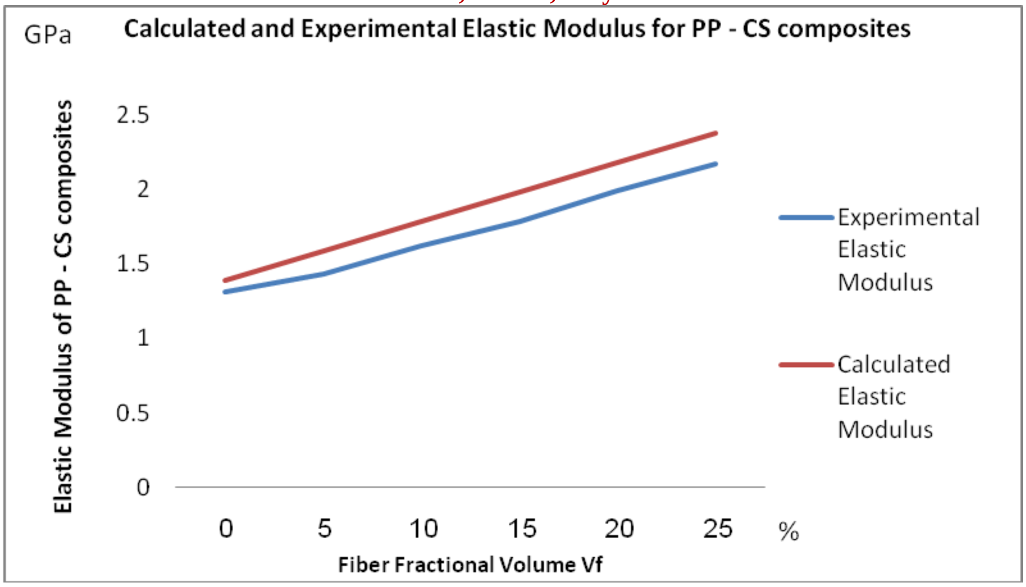

Fig 9: Experimental and Calculated Elastic Modulus for PP –CS Composites

It is quite clear from the above figures that there are linear improvement of the mechanical properties of the composites based on the increase of the fiber fraction volume. The tensile strength and elastic modulus results of PP and its composites at different cotton stalks fibers (CS) contents are given in Table 4. This shows that the tensile strength tests results increased steadily from 22.23 up to 38.00 MPa which amounts to 49.3% enhancement against 25% fiber addition. While in the theatrical calculation the strength enhanced from 27.5 up to 41.1 which equivalent to 38.6% at 25% fiber addition. and 19.77–8.42%, respectively. This reveals that incorporation of CS had increased the tensile strength and elastic Modulus.

IV. CONCLUSIONS

These results stated above proved that reinforcing PP with cotton stalks fibers is a feasible composite and gives increased mechanical properties based on its fiber content. Two ultimate goals will be achieved from this composite, viz. enhancing the properties of PP as highly demanded material beside make use of agricultural residuals mostly accumulating and loading the environment.

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