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Design and Development of Bamboo Link Mechanism using Synthesize Adhesive at Bamboo Joints

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Bamboo articles used in the daily life make the market more profitable because of the easier availability with low cost and comfort with the environment without any type of pollution. The bamboo is used as the constructional materials from the initial period in the rural areas and even in the modern society for the decorative appearance mostly used as the mechanical properties of bamboo is concerned compared to the mild steel used in many applications. This makes the development of bamboo articles, constructional and mechanism purpose more beneficial in the rural areas and provided the job opportunities and livelihood in the rural communities. Developed adhesive is prepared with the replacement of bamboo dust and the replacement of 25% phenol formaldehyde. Developed adhesive is applied to the mechanism made from bamboo links instead of applying adhesive available in market to test the performance of developed adhesive in predict the mechanical properties. It is found that developed adhesive is good for structural members of which the mechanism is fabricated in terms of tensile, shear and compressive strength compared to available adhesive considering cost and manufacturing. The paper details the performance of the six-bar chain mechanism made from the bamboo linkages and bamboo joints with the applying appropriate developed bamboo adhesive to the bamboo joints. The experimental setup made from the bamboo links using synthesize adhesive is six bar mechanism which is tested with the varying load 5 to 9.5 Kg to predict a performance for six bar chain mechanism and observed the behavior related to angle of oscillation, weight bearing capacity, link length limitation at constant and varying speeds 12-16 rpm. The experimental observation is recorded and based on this recorded data a mathematical model is developed to correlate a relationship between causes and effect involved in the experimentation, so that effective measures can be taken to control required performance for light duty machines.

Keywords: Adhesive, Bamboo, Mathematical modeling, Mechanism, Joinery

1 Introduction

Bamboo is an important resource in our socio-economic and cultural context. It is a fast-growing, widespread, renewable, versatile, and environment-enhancing resource. Bamboo can be harvested in 3-4 years from the time of plantation[1]. Since centuries bio-based adhesives were used for bonding wood but in the 20th century synthetic adhesives took over because of more effective and low-cost. This is the principal reason for the replacement of wood by bamboo. Bamboo being a non-wood lignocellulosic material is used widely for construction, furniture and as a material for many daily domestic uses. Bamboo resource development will help in employment generation and sustainable livelihoods in rural communities[2]. Mechanical properties of bamboo are so similar to those of steel that it has largely supplanted steel in construction. Properly chemically treated bamboo species have various properties fairly enhanced compared to steel material which shows that chemically treated bamboo species can be used as the material to replace steel and/or plastic as a new material for parts of machinery. The properties which can be enhanced are (i) yield strength in tension/compression/shear[1,2] (ii) abrasion and wear resistance[3,4] (iii) impact resistance[5] (iv) moisture absorption resistance[6,7] (v) heat resistance[6] (vi) enhancing dielectric strength[8], etc. If this be the case, it is necessary to try out such appropriately chemically treated bamboo as a new material for parts of machinery[9-11]. Moreover, it is also necessary to confirm suitability of properly developed adhesives to join the parts of machinery made from bamboo.

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This second aspect is a focus in present investigation, wherein a six link one degree of freedom planar linkage[12] is investigated experimentally to study the response of properly chemically developed adhesive[13] joint for two parts of one coupler of this linkage. The material of the links except the frame is a bamboo. The development of bamboo materials emphasis to design the mechanism of the machines with the same strength as the present structural members. The appropriate chemically treated bamboo is used for the structural members with appropriate bamboo developed adhesives for the bamboo joints is the new enhancement in the development mechanisms leads to reduction in cost and industrial pollution created during processing steel. The adhesive developed is tested on the timber bamboo[14,15] available in Vidarbha region of India. Cost involved in the development of new adhesive is almost 35 percent less compared to the market adhesive as raw materials used is bamboo dust, flour and some suitable chemicals. Developed adhesive can be used for the other bamboo varieties with suitable chemical treatment.

2 Materials and Methods

2.1 Proposed mechanism and experimental setup

Figure 1, is the six-chain mechanism[16] made of bamboo links with the appropriate bamboo developed adhesive operated by the electrical motor. The linked crank rocker six link chain is loaded with a band brake with time variation forces at points O_1, O_2 and O_3appliedfrom the six chain bar mechanism. The proposed mechanism is tested with varying the dimension, cross section of the links and experimentation is done by varying the dead load and the corresponding the speed and number of rotation is measured. The various parameters are measured with different adhesives available in market, varying a frame structure geometry and dissimilar impact load upon a frame. The experimentation is done by investigating the various parameters. Mathematical model would be formulated on the basis of the experimental finding[17-19].

Figure 2 is a schematic line sketch of an experimental set-up. It involves a six-link planar chain $O_1ABO_2CO_3$ where in link lengths O_1A = 5.0 cm; AB = 10.0 cm, O_2B = 12.0 cm, BC = 36.0 cm, O_3C = 15.0 cm, $O_1O_2O_3$ = 55.0 cm. The link cross sections of O_1A, AB, O_2B, O_3C are rectangular 3.0 cm height x 2.0 cm thickness a dimension perpendicular to the plane of motion which is vertical. The link BC 36.0 cm long is in two identical pieces with adhesive joint having dimensions 11.0 cm along BC, height = 3.0 cm and thickness of adhesive = 0.2cm. This joint is right in the middle of link BC as shown in Figure 3.

The output shaft is carrying a pulley with diameter = 15.0 cm. A rope is placed round the pulley with a dead weight W to generate resisting torque. The weights at a time tried to develop torque are 5.0 kgf, 5.5 kgf, 6.0 kgf, 6.5 kgf, 7.0 kgf, 7.5 kgf, 8.0 kgf. The linkage is SDOF system[11] with driving crank O1A. The driving energy source is DC motor, 12 V and 75 watts.

The adhesive is prepared as detailed below:

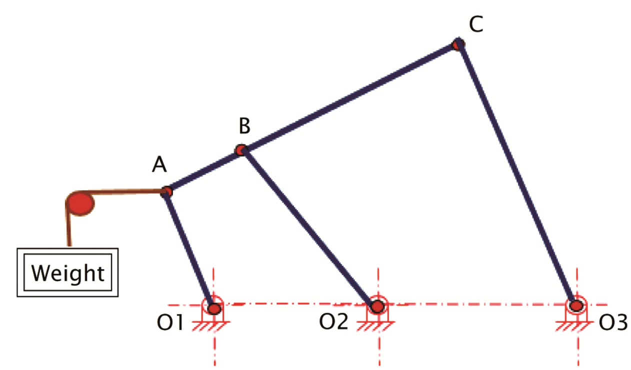

Fig. 1 — Proposed six bar chain mechanism usinglinks of bamboo.

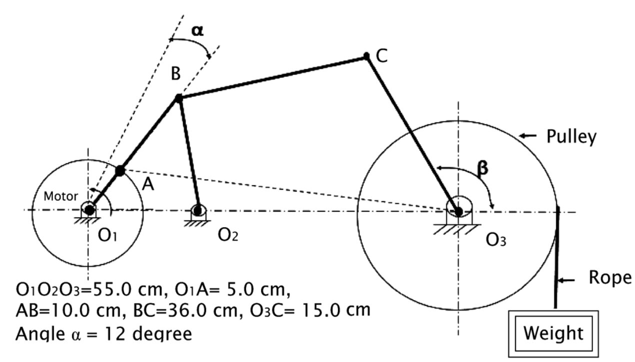

Fig. 2 — Schematic diagram of an experimental set-up (not to scale).

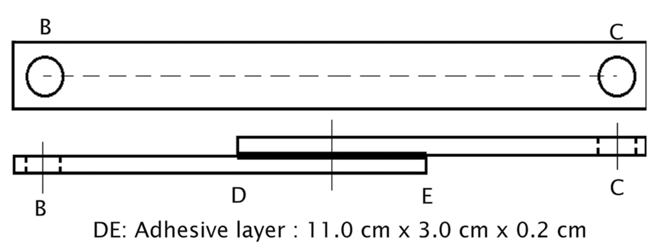

Fig. 3 — Adhesive layer in link BC (not to scale).

- Liquification of bamboos. It is the mixture of Glycerol and Sulfuric acid.
- The mixture of 25% liquified bamboos and 75% Phenol Formaldehyde.
- Addition of 5% wheat flour.
- Above mixture is heated at 180^0 in oil bath for adhesive preparation.

The weight of the adhesive is 21.0 gms. Modulus of elasticity of adhesive is 979.0 kgf/cm^2. Modulus of elasticity of bamboo is 20.0 x $10^4 kgf/cm^2$. The photograph of the set-up is displayed in Figure4.

Since bamboo's mechanical qualities are so similar to those of steel, it has largely supplanted steel in construction[20-22]. To compare the Tensile Properties of bamboo to those of steel, many samples of both materials were tested and studied[23]. The effectiveness under diverse loads and speeds was tested by using a six-chain mechanism made of bamboo links joined together with an adhesive. The experimental data is used to inform a mathematical model of the relationship between the dependent variable (shear strength) and the independent pie variables (operational speed, weight applied, glue applied, link length, cross sectional area). How well bamboo performs is shown by the relative importance of the various pie terms as measured by their respective indexes.

Fig. 4 — The photograph of the set-up.

2.2 Formation of dimensionless group for differentπ terms

The mechanical linkages that allow the mechanism to function in the 0-10 hp range are made possible by the use of chemical treated bamboo and suitable adhesives for structural parts made of bamboo[20,25]. The frame of the mechanism is subjected to the severe unpredicted random vibrations into a frame structure. The purpose of these experiments was to demonstrate the effectiveness of employing chemically treated bamboo as a raw material in conjunction with adhesives that are compatible with the material.

Interacting physical systems are the source of the characteristics disrupting the effectiveness of the phenomena under examination[26, 27]. Shear stress to tensile yield strength ratio is the dependent or response variable.

2.3 Development of dimensionless group of π terms

The dependent and independent variables are formulating in the table 2 and table 3:

Table 1 — Various dependent & independent variables considered in study

Description	Variables	Symbol	Dimension
Shear stress to tensile yield strength Ratio	Dependent	Pi_D	$[M^0 L^0 T^0]$
Mechanism length O_1O_3	Independent	M1	$[M^0 L^1 T^0]$
Mechanism length O_1A	Independent	M2	$[M^0 L^1 T^0]$
Mechanism length AB	Independent	M3	$[M^0 L^1 T^0]$
Mechanism length O_2B	Independent	M4	$[M^0 L^1 T^0]$
Mechanism length BC	Independent	M5	$[M^0 L^1 T^0]$
Mechanism length O_3C	Independent	M6	$[M^0 L^1 T^0]$
Glue Film Depth	Independent	d	$[M^0 L^1 T^0]$
Glue Film Thickness	Independent	t	$[M^0 L^1 T^0]$
Glue Film length	Independent	l	$[M^0 L^1 T^0]$
Elasticity Adhesive	Independent	E_{adh}	$[M^1 L^1 T^{-2}]$
Elasticity Bamboo	Independent	E_b	$[M^1 L^1 T^{-2}]$
Consider applied	Independent	w	$[M^1 L^1 T^{-2}]$
Quantity (adhesive)	Independent	m_{adh}	$[M^1 L^0 T^0]$
Shear stress	Independent	S	$[M^1 L^{-1} T^{-2}]$
Instantaneous breaking force	Independent	F_{65}	$[M^1 L^1 T^{-2}]$
Oscillating angle	Independent	β	$[M^0 L^0 T^0]$
Yield strength (Tensile)	Independent	Ss	$[M^1 L^{-1} T^{-2}]$

Table 2 — Dimensionless π terms of Independent Parameters

S. N.	Dimensionless ratios (Independent)	Nature
01	$P_1 = [(M_2/M_1)(M_3/M_1)(M_4/M_1)(M_5/M_1)(M_6/M_1)(d/t)(l/M_1)]$	Corresponding to link length
02	$P_2 = [E_{ADH}/E_B]$	Corresponding to elasticity
03	$P_3 = [(t*M)/(mass_{(adhesive)}*M_1]$	Corresponding to overlap joint
04	$P_4 = [\beta*(\Pi/180)]$	Corresponding to angle

Table 3 — Output (Dependent) terms

S. N.	Outputπ terms	Nature
01	$Z_1 = [S/Ss]$	Shear stress to tensile yield strength Ratio

2.4 Field data based model development

One dependent π terms (Output) and four independent pie terms (P1, P2, P3, P4) have been recognized for formulation of model.

Output = function of (P1, P2, P3, P4)

Where,

Output = PD, First dependent π term= S/Ss

PD = K* [(M2/M1)(M3/M1) (M4/M1)(M5/M1) (M6/M1)(d/t)(l/M1)]a,[EADH/EB]b, [(t*M)/(adhesive mass)*M1]c, [β*(Π/180)] d …(1)

PD=K1*[(P1) a1*(P2) b1*(P3) c1*(P4) d1] … (2)

Equation 2 is expressed as follows to determine the a1, b1, c1, and d1:

ΣP = nK1 + a1*ΣA + b1*ΣB + c1*ΣC + d1* ΣD

ΣPD*A = K1*ΣA +a1*ΣA*A + b1*ΣB*A + c1*ΣC*A + d1* ΣD*A

ΣPD*B = K1*ΣB +a1*ΣA*B + b1*ΣB*B + c1*ΣC*B + d1* ΣD*B

ΣPD*C = K1*ΣC +a1*ΣA*C+ b1*ΣB*C + c1*ΣC*C + d1* ΣD*C

ΣPD*D = K1*ΣD +a1*ΣA*D + b1*ΣB*D + c1*ΣC*D + d1* ΣD*D

A matrix version of the aforementioned equations is given for your convenience.

X1 = inv (W) x P1

A matrix W with elements K1, a1, b1, c1, and d1 of constant value might look like this:

P1 is the matrix on L H S and

X1 is the matrix of values of K1, a1, b1, c1 and d1

Then, the matrix obtained is given by,

Matrix

The matrix's unknowns are stated as once the matrix has been solved.

K1 = 0.1764, a1 = 2.9810, b1 = -1.7182, c1 = 0.8010 and d1 = 2.9245

The precise model form achieved is as follows:

PD= 0.1764*(P1) 2.9810 *(P2) -1.7182 *(P3) 0.8010 *(P4) 2.9245

3 Result and Discussion

The correct power of term P1 is 2.9810 which is large compared to other power term. The term P1 is related to the linkages dimension of the mechanism of the experimental setup which is most prompting term in this model and effecting the output of the mathematical model that a shear stress to yield stress ratio. The value is positive means it is directly proportional to the output affecting the output in the proportional form[29]. The performance of the mechanism means the controlling the ratio of shear stress to yield stress is depending on the second term that is P4 having the power index of 2.9245 corresponds to the group of terms such as link length, cross-sectional area of link, material selected and weight of the link. Overall the both the terms indicate that shear stress increased with the increase in the process parameters[30].

Similarly, output is changing with the term P3 of the mathematical model which is smallest compared to other terms having the value 0.8010 which indicates the less affecting the pie terms of the mathematical model on the corresponding output the ratio of shear stress PD also indicates that the term P4 is positive mean it is directly proportional to the output with less influences[28].The term P2 is negative that is -1.7182 is inversely proportional to the output which indicates that elasticity is indirectly proportional to the ratio of shear stress to the yield stress. This indicates that with increase in the elasticity of adhesive decreases the shear stress and increases the yield stress[31]. Similarly, elasticity of the material is directly proportional to the ratio shear stress to yield stress.

4 Conclusion

Synthesize developed adhesive is used for a coupler of a 6-link bar mechanism shows that the kinematic chain is having sustainability of around 20 cycles of the various varying forces when coupler maximum force is 40.0 kgf. All links are made from timber bamboo except the frame. Execution of experimentation is as per design of experimentation, methods of test data checking and rejection, formulation of models. reliability of models and optimization of models. All these steps are included and executed as per the approach of "Theories of Engineering Experimentation" by H. Shenck Jr. Based on the complete analysis and desired properties of bamboo with the adhesives is suitable for the mechanism manufacturing, bamboo furniture, structural members with sufficient load carrying capacity. Further enhancement of bamboo material with synthesizes adhesives can be recommended for the construction materials, machinery tools, many more such applications.

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