Obrabotka metallov (tekhnologiya, oborudovanie, instrumenty) = Metal Working and Material Science. 2023 vol. 25 no. 3 pp. 117–125
ISSN: 1994-6309 (print) / 2541-819X (online)
DOI: 10.17212/1994-6309-2023-25.3-117-125

NSTU NETI

Obrabotka metallov -
Metal Working and Material Science

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# Analysis of mechanical behavior and free vibration characteristics of treated Saccharum munja fiber polymer composite

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ARTICLE INFO

*Article history*:
Received: 24 May 2023
Revised: 06 June 2023
Accepted: 13 June 2023
Available online: 15 September 2023

*Keywords*:
*Saccharum munja*
Compression moulding machine
Natural frequency
Damping
Tensile test
*ANOVA*

*Acknowledgements*
Authors are very thankful to *Rajkiya Engineering College*, Azamgarh for providing laboratory for research work.

ABSTRACT

**Introduction.** With increasing environmental concern nowadays, researchers are studying new alternating materials that can meet the society needs and are extracted from renewable and biodegradable resources. The various natural fibers have been investigated by researchers to replace synthetic ones. **The purpose of the work.** In present study, treated saccharum munja fibers considered as reinforcement material in Particulate (*PC*), Short and Random (*SRC*) and in Unidirectional (*UDC*) form along with *AW106* Resin and *HV953*. The paper assesses the mechanical properties of *Munya* fibers (*Saccharum munja*). Initial six natural frequencies along with corresponding damping factors are measured to analyze the possibility of using a composite material. **Research methods.** A compression molding machine was used to form laminated composite materials. Surface treatment of fibers removes the dust, lignin and hemicellulose, which improves mechanical and free vibration properties. **Results and Discussion.** Tensile and flexural test shows the highest value of strength 170 MPa and 143 MPa in case of *UDC* composite, and the lowest in the case of *PC*. Addition of munja fiber to epoxy matrix enhances the fiber matrix adhesion bonding. The *PC* composite shows better value of damping than *SRC* and *UDC* composite. The highest natural frequency 43, 233, 298, 849, 918 and 1,440 Hz obtained in case of *UDC* irrespective of all modes. The results of the free vibration analysis show that *Saccharum Munja* fiber composite may be used as structural material. Analysis of variance *(ANOVA)* shows that the experimental results output in case of tensile and flexural teste are significant.

**For citation:** Singh S.P., Hirwani C.K. Analysis of mechanical behavior and free vibration characteristics of treated Saccharum munja fiber polymer composite. *Obrabotka metallov (tekhnologiya, oborudovanie, instrumenty) = Metal Working and Material Science*, 2023, vol. 25, no. 3, pp. 117–125. DOI: 10.17212/1994-6309-2023-25.3-117-125. (In Russian).

## Introduction

In recent years, natural fiber has become a viable alternative material. Natural fibers are useful materials and are able to replace the synthetic ones [1]. Recent studies show that natural fibers can replace even glass fiber [2]. Due to natural fibers modern materials are created that can replace existing synthetic fibers. Because of the intensifying energy crisis and increased environmental awareness, much attention is paid to natural fibers and various composites based on it [3]. *Saccharum munja* grass fiber extraction and use in composite materials [4]. Many studies have been carried out on polymer composite materials based on natural fibers due to its good mechanical properties. In the last 20 years, there has been a great interest in the use of agricultural products that are cellulosic and lignocellulosic for the use of composite applications, particularly for matrix reinforcement [5]. Unlike synthetic fibers such as Kevlar, nylon, polyester, rayon,

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glass and carbon, natural fibers have many advantages. It can be stated that chemical composition and cell structure of natural fibers are quite complicated [6]. In addition to the advantages of using environmentally friendly materials, there are certain difficulties, such as relatively poor “matrix-fiber” interfacial adhesion when reinforcing and increased moisture absorption. Potential resource materials for various technical applications, including electrical, automotive, the packaging sector, and domestic use, include sisal, abaca, pineapple, agave, and banana fiber [7]. Polymer composites reinforced with synthetic fibers have excellent mechanical properties and lightweight construction [8]. The distribution of the fibers and the mechanical properties of the composite materials have been improved by treating the fibers with clay with an inorganic additive, although an additional mineral additive is probably needed in this area [9]. The automotive industry has recently become interested in natural fiber-based composite materials for a number of reasons, including improved vehicle fuel efficiency, and increased public concern over ecological sustainability. Natural fiber-reinforced composites are being used more and more in the construction and transportation sectors. Therefore, it is crucial to understand how it behaves in a fire [10].

Addition of rice bran into polylactic acid matrix (*PLA*) improves the mechanical properties and natural frequencies of rice bran *PLA* composite that can be used in 3D-printing [11]. The addition of short alpha fibers in epoxy makes composite more deformable and flexible due to lower stiffness values and high strain [12]. Based on the results of the analysis of free vibrations of the *bamboo* fiber composite, it is recommended for use in the transport and construction industries [13]. The surface treatment of natural fiber improves its mechanical and free vibration properties [14–17]. The free vibration values of flex fiber composite are dependent upon fiber direction and thickness [18]. The natural frequency of *aloe vera* fiber composite is affected by fiber stacking sequence, composite thickness and end conditions [19]. The natural frequency of composite beam increases with an increase in composite thickness regardless of boundary conditions. It also improves the modal damping of composite material [20, 21].

From the above literature, it can be concluded that the greatest amount of work has been done by researchers on the study of the mechanical properties of natural fibers composite materials; however, less attention has been paid to works related to the characteristics of free vibrations. In this paper, the mechanical properties of a polymer composite material based on *Saccharum munja* fibers were investigated along with its free vibration characteristics. Based on resonance peek in frequency response, the initial six-mode natural frequency with corresponding damping factors was obtained using an experimental setup. *ANOVA* analysis was performed to check the level of significance of the tensile and flexural tests.

## Research Methods

Particulate (*PC*), short and random (*SRC*) and unidirectional (*UDC*) treated *Saccharum munja* fibers are considered as the reinforcing component of the composite material, while *AW106* resin and an appropriate amount of *HV953* hardener supplied by Prakash (Azamgarh, Uttar Pradesh, India) were used as matrix material. *Saccharum Munya* fibers were extracted from a dry plant obtained near the banks of the *Gagara River* (Gonda, Uttar Pradesh, India). *Munya* fibers were washed with 1 M *NaOH* solution for 30 minutes and then washed again in distilled water for 1 hour to remove traces of *NaOH*. Next, the washed fibers were dried in a hot cloth at 120 °C for 30 minutes. Washed again in distilled water and dried further in a hot cloth to remove any remaining *NaOH* and water content on the fiber surface. Compositions with different volumetric ratios used in this study are presented in Table 1. A compression molding machine (fig. 1) was used to form laminated composite materials (*CM*) with a size of 30×30×3 cm. First, a known amount of resin and hardener was poured into the mold cavity and waited for 90 minutes for solidification to begin. Then a mixture of resin and fiber was poured and again waited for 90 minutes. The mixture was compressed at a pressure of 120 bar and held at 800 °C for 48 hours. The processes of fabrication of *Munja* fiber composite laminates are presented in fig. 2. The fabricated laminates were cut in different shapes and sizes in accordance with *ASTM* standards for further analysis.

*ASTM D638* was used for tensile testing of rectangular fiber-polymer composite specimens with a gauge length of 57 mm. The test was carried out on a digital universal testing machine (*UTM*) manufactured by

Table 1

**Composite composition (by Volume)**

| Specimen No. | Material Used | Nomenclature | Specification | Volume Ratio |
|---|---|---|---|---|
| 1 | Neat Resin, $dm^3$ | *NR* | *AW106* | 1 |
| 2 | Hardener, $dm^3$ | | *HV953* | 1 |
| 3 | Particulate *Munja*, % | *PC* | - | 20 |
| 4 | Unidirectional *Munja*, % | *UDC* | - | 20 |
| 5 | Short & Random *Munja, %* | *SRC* | - | 20 |

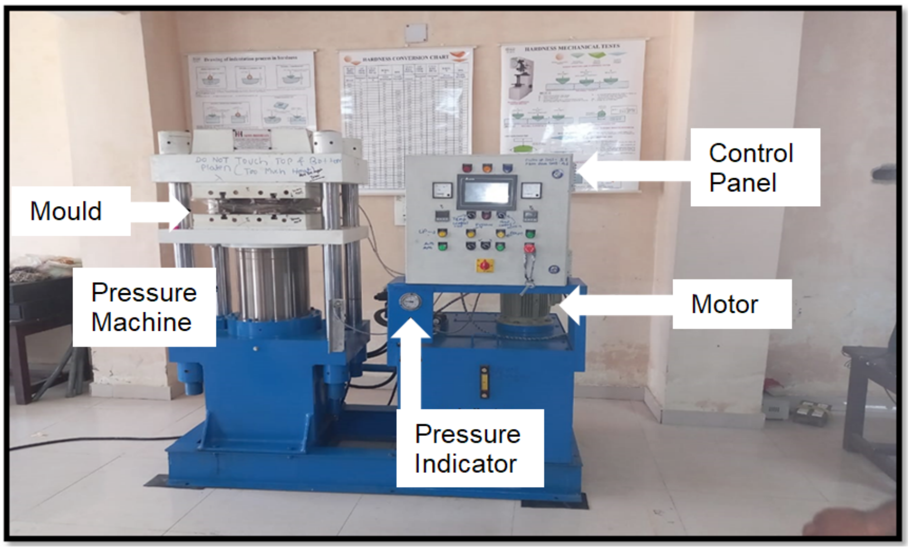



*Fig. 1.* Compression moulding machine

*Aimil private limited* (Bangaluru, India) with position accuracy 0.001 mm and speed accuracy 0.005 %. The test specimen was first clamped between the *UTM* clamps and then subjected to an increasing load at a tensile rate of 3 mm per minute until the specimen was broken. Five different specimens were cut from five different layered *CMs* and used for tensile tests to ensure test reproducibility and take into account average values.

The flexural test was performed on the same digital universal testing machine (*UTM*) on specimens with tufted *Munya* fibers in accordance with *ASTM D790* specifications. For each combination, five specimens, 150×15×3.5 mm, were considered and average results were taken to ensure test reproducibility, with the flexural test speed matching that of the tensile test.

The characteristics of free vibrations are analyzed using the experimental setup shown in fig. 3a and 3b, respectively, to estimate the initial six natural frequencies and the corresponding damping factor using the frequency response and using the fitting circle method, respectively. Based on mass and stiffness matrix resonance response, the six visible resonance peek are considered in this study. The major aim of conducting free vibration test is to see the application of this composite as structural material or as damping material. The test specimen was in the form of a

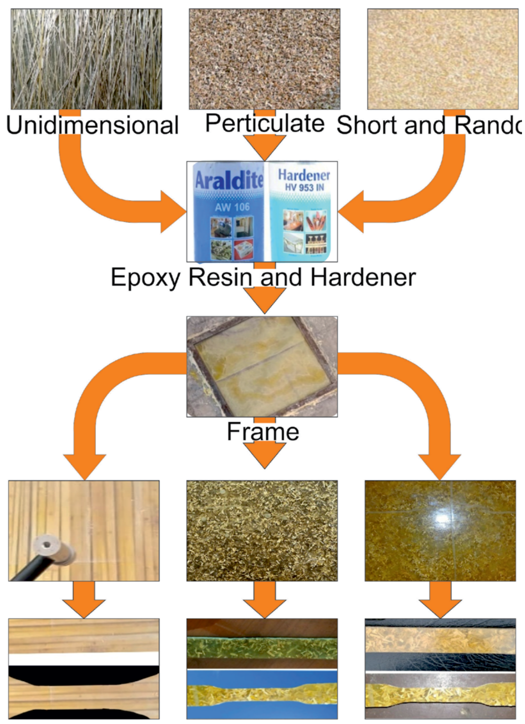
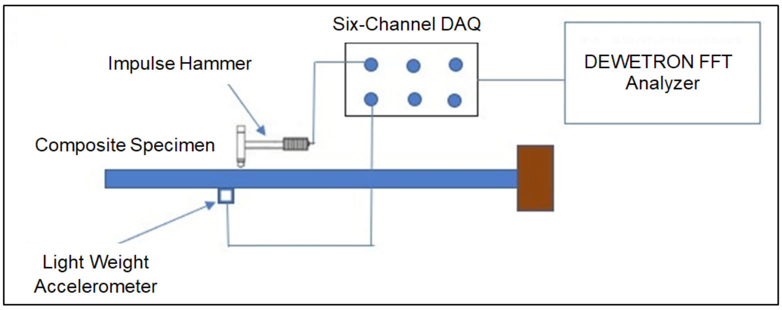
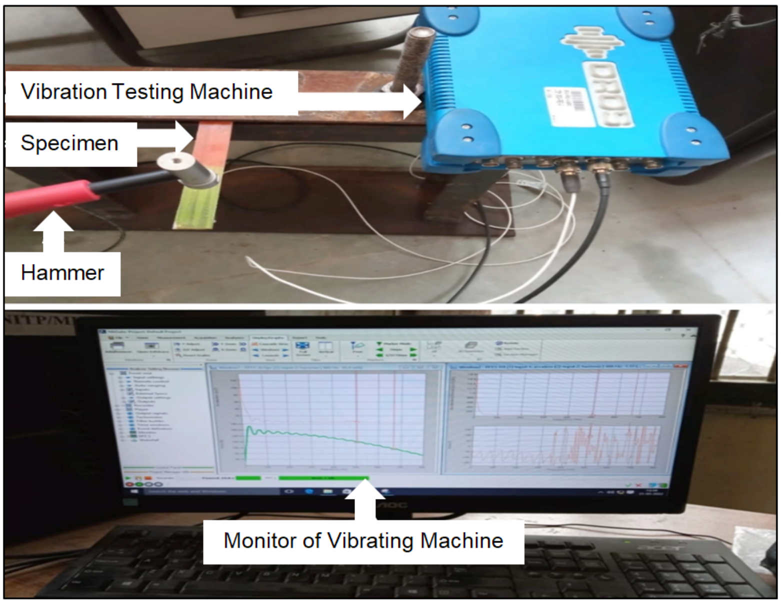



*Fig. 2.* Fabrication process




*a*




*b*

*Fig. 3.* Vibration testing:
*a* – block daigram of free vibration; *b* – free vibration testing

cantilever beam with dimensions of 160×10×3.5 mm. The corresponding damping factors were calculated using the fixed circle method, and the equation used to calculate the damping factors is shown below.

$$\zeta = \frac{\omega_2^2 \quad \omega_1^2}{2\omega_0 \left[ \omega_2 \tan \dfrac{\alpha_2}{2} + \omega_1 \tan \dfrac{\alpha_1}{2} \right]}.$$

## Results and Discussion

### *Tensile Test*

The results of the tensile test of the dumbbell-shaped specimens (fig. 4) indicate that the mechanical properties of the layered *CM* increase when fibers are added to the matrix. The ultimate strength of *NR* is 62 MPa, and when 20 % of *Munya PC* fibers are added to the resin, the ultimate strength increases to 85 MPa. The addition of 20 % *SRC* fiber to the epoxy resin increases the ultimate strength to 123 MPa. The addition of 20 % *UDC* fiber to the epoxy resin also increases the tensile strength to 170 MPa. The highest ultimate strength of *UDC* composites is 170 MPa, which is 28 % more than the ultimate strength of *SRC* composites, 50 % more than the strength of *PC* composites, and 63 % more than the strength of *NR*. The addition of *Munya* fiber to the polymer matrix increases the permanent deformation of the composite polymer based on the *Munya* fiber. The ultimate strength of 85 MPa was in the case of *PC*, which is 28 % greater than the ultimate strength of *NR*.

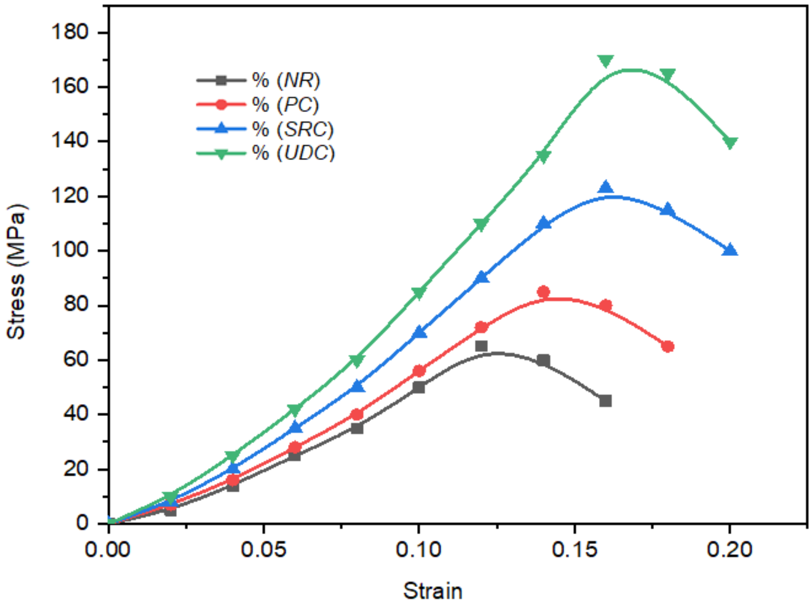



*Fig. 4.* Tensile behavior of *Saccharum Munja* fiber polymer composite

### *Flexural Test*

A specimen of the *Munja* fiber polymer composite was subjected to a flexural test using a digital universal testing machine (*UTM*). The test results are shown in fig. 5. It was found that the highest flexural strength is characteristic of the *UDC* composite and was 143 MPa when 20 % *UDC* fiber was added to the epoxy resin; the lowest flexural strength was recorded for *NR* and amounted to 65 MPa; and the flexural strength of two specimens of *SRC* composite and *PC* composite was 113 MPa and 102 MPa using 20 % *SRC* and *PC* fibers, respectively. The flexural strength of *UDC* is 21 % greater than the flexural strength of *SRC* and 28 % greater than the flexural strength of *PC*, and ~54 % greater than the flexural strength of *NR*.

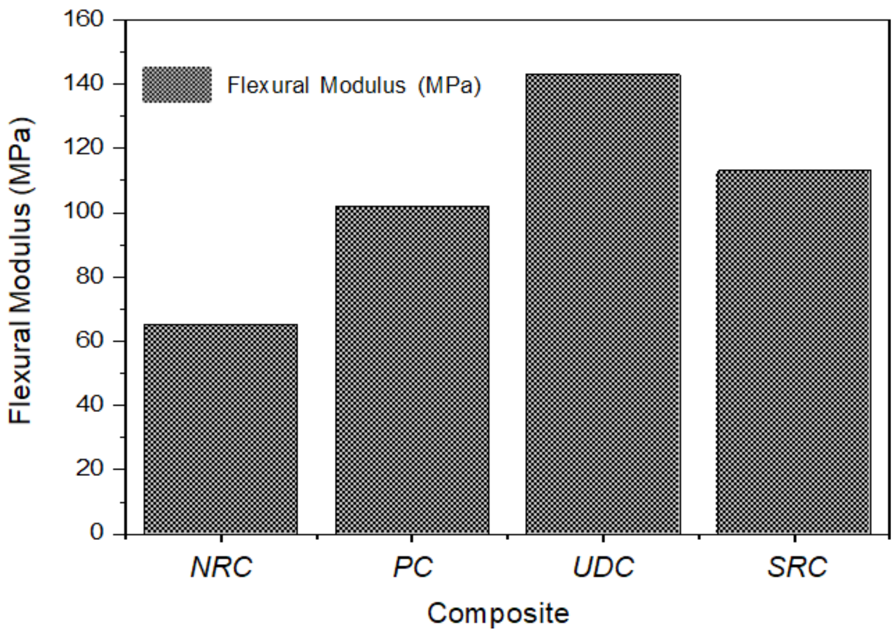



*Fig. 5.* Flexural behavior of *Saccharum Munja* fiber polymer composite

### *Free Vibration Test*

The results of tests for free vibrations, carried out on an experimental setup, are presented in table 2. In this experiment, six natural frequencies were obtained, and damping factors was obtained with the help of fit circle. The first mode of the six frequencies for *NR*, *PC*, *SRC*, and *UDC* is 19; 32; 39; 43 and damping factors are of 0.160; 0.074; 0.065; 0.051 respectively and the last mode (with damping factors) are 506 Hz (0.022); 1052 Hz (0.017); 1124 Hz (0.015); 1440 Hz (0.012). The damping factor values obtained indicate the practical utilization of *Munja* fiber polymer composite in various fields such as automobile, safety products, production house, etc.

Table 2

**Free vibration behavior (also known as Dynamic Behavior Analysis) of *Saccharum Munja* fiber polymer composite**

| Composite | Natural Frequency and damping factor of *Saccharum Munja* fiber | | | | | |
|---|---|---|---|---|---|---|
| | Mode 1 | Mode 2 | Mode 3 | Mode 4 | Mode 5 | Mode 6 |
| NR | 19<br>0.160 | 95<br>0.074 | 125<br>0.059 | 353<br>0.033 | 380<br>0.029 | 506<br>0.022 |
| PC | 32<br>0.072 | 172<br>0.045 | 213<br>0.050 | 611<br>0.021 | 677<br>0.023 | 1,052<br>0.017 |
| SRC | 39<br>0.065 | 187<br>0.039 | 233<br>0.030 | 689<br>0.020 | 741<br>0.018 | 1,124<br>0.015 |
| UDC | 43<br>0.051 | 233<br>0.031 | 298<br>0.021 | 849<br>0.016 | 918<br>0.015 | 1,440<br>0.012 |

### *ANOVA Analysis*

Analysis of variance (*ANOVA*) was performed to test the significance of the obtained results for tension and flexing with a 5 % alpha level. The probability value in both cases is less than 0.05, which confirms the significance of the obtained experimental results in tensile and flexural tests (Table 3).

Table 3

***ANONA* analysis *of Saccharum munja* fiber polymer composite**

| | Source of Variation | *SS* | *df* | *MS* | *F* | *P*-value | *F* crit |
|---|---|---|---|---|---|---|---|
| Tensile Test | Between Groups | 15,610.95 | 4 | 5,203.65 | 2,973.514 | 0.0000 | 3.238872 |
| | Within Groups | 28 | 16 | 1.75 | | | |
| Flexural Test | Between Groups | 15,610.95 | 4 | 5,203.65 | 2,973.514 | 0.0000 | 3.238872 |
| | Within Groups | 28 | 16 | 1.75 | | | |

## Conclusions

From the above study, it can be seen that the addition of *Saccharum munja* fiber to the epoxy matrix improves its mechanical properties as well as free vibration characteristics. The highest tensile and flexural strength values are observed for the *UDC* composite, followed by the *SRC* composite; and the lowest value was obtained in the case of the *PC* composite. Keeping the natural fiber in the core of the composite promotes better load transfer resulting in higher properties. Due to the highest adhesion of the fiber to the matrix, in the case of the *UDC* composite, the best mechanical and free vibration behavior is provided. The natural frequencies corresponding to all mode shapes are better detected in the case of a *UDC* composite. The *PC* composite shows the best damping factor values. Analysis of variance (*ANOVA*) shows that all tensile and bending results are significant.

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## Conflicts of Interest

The authors declare no conflict of interest.