JCMM

Journal of Computers, Mechanical and Management

Volume 1, Issue 2
2022

Journal of Computers, Mechanical and Management

Journal homepage: www.jcmm.co.in

JCMM
Journal of Computers, Mechanical and Management

Editorial Comments for JCMM Volume 1 Issue 2

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The second issue of the Journal of Computers, Mechanical and Management presents a diverse range of research topics, highlighting the latest advancements in the field of technology. The first article, "Transparent Sheet Heater with Flexibility based on Poly (vinyl alcohol) Embedded with Sodium Tungstate" by Joshi et al. deals with the development of transparent sheet heaters that can be used in various applications such as building heating, automotive, and aerospace industry. The authors have used a unique combination of polyvinyl alcohol and sodium tungstate to achieve flexibility and transparency in the sheet heater. This is a novel approach and the results obtained are quite promising [1]. The second article, "CLEAROSO: A Cleaning Robot for the Solar Panels" by Deshmukh et al. presents the design and development of a cleaning robot for solar panels. With the increasing demand for renewable energy sources, it is crucial to ensure that the efficiency of solar panels is not compromised by dirt and dust accumulation. The authors have proposed a robot that can clean solar panels effectively and efficiently. This is an important contribution to the field of renewable energy, and the results obtained are quite impressive [2].

The third article, "SASHAKT: A Job Portal for Women using Text Extraction and Text Summarization" by Kaur et al. presents the development of a job portal specifically for women using text extraction and summarization techniques. The authors have used natural language processing techniques to extract relevant information from job descriptions and have used text summarization techniques to present the information in a concise and easy-to-understand format. This is a valuable contribution to the field of human resources, and the results obtained are quite promising [3]. The fourth and final article, "A Comprehensive Review of Banana Fiber-Reinforced Composites: Properties, Processing and Applications" by Singh et al. is a review paper that presents a comprehensive overview of the properties, processing, and applications of banana fiber-reinforced composites. The authors have reviewed the literature on this topic and have highlighted the potential of banana fiber as a reinforcement material in composites. This is an important contribution to the field of materials science and engineering [4].

In conclusion, the second issue of the Journal of Computers, Mechanical and Management presents a diverse range of research topics, highlighting the latest advancements in the field of technology and management. We would like to encourage prospective authors to consider publishing their research in the upcoming issues of the Journal of Computers, Mechanical and Management. The journal welcomes high-quality research articles and review papers.

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Editor-in-Chief
Journal of Computers, Mechanical and Management [JCMM]
GADL

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Published: 01 November 2022

DOI: 10.57159/gadl.jcmm.1.2.22038.

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Journal of Computers, Mechanical and Management

Journal homepage: www.jcmm.co.in

Volume 1 Issue 2

Transparent Sheet Heater With Flexibility Based on Poly (Vinyl Alcohol) Embedded With Sodium Tungstate

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Abstract

Transparent sheet heaters with flexibility (TSHF) exhibiting improved mechanical and thermal stability were made by adding sodium tungstate (NaW) into poly (vinyl alcohol) (PVA) films by solution coating and solvent evaporation method. The prepared TSHFs were characterized by scanning electron microscopy (SEM) to understand the surface morphology better. Further UV-Visible measurement was carried out. The electric conductive properties were assessed by using the four-probe experiment. An infrared thermometer was used to measure the temperature of the TSHFs. The fabricated NaW/PVA hybrid TSHFs demonstrated elevated heating temperatures, 96 °C at a minimum input voltage of 6 V with a minimum response time ($T < 40$ sec), lower power consumption (162 °C cm^2 W^{-1}) and process stability after repeated use when compared to ITO/FTO heaters. The bending resistance of the NaW/PVA hybrid TSHFs was excellent. The change in sheet resistance after 1000 cycles of outer bending was less than 18%. The effective embedding of the NaW network in the transparent nascent PVA film's surface reduced surface roughness ($R_{\text{rms}} < 1$ nm) and improved oxidation and moisture resistance. The produced TSHFs exhibited excellent heating qualities, with their transparency demonstrating remarkable flexibility. The potential uses of NaW/PVA include defogging windows and thermochromic.

Keywords: Transparent Thin-Film Heaters; Flexible Transparent Electrodes; Conductive Films; Poly(Vinyl Alcohol); Sodium Tungstate

1 Introduction

Transparent film heaters (TFHs) have received much attention for a variety of applications, including outdoor displays, window defogging, and thermal-based sensors [1–5]. A typical commercial film-like heater is made of a metallic wire based on a Fe-Cr-Al alloy [6], which, however, is rigid and has a low heating efficiency. Another commercial metallic film heater with similar shortcomings is a patterned copper foil thin film [7]. Tin-doped indium oxide (ITO) transparent conductive film has also been widely used as a heating element because of its high optical transmittance in the visible region, high electrical conductivity, and environmental stability [8–10]. However, due to indium scarcity, crack formation during mechanical bending, and delayed thermal response, ITO is considered prohibitively expensive, particularly in large areas and flexible applications [11–15]. Several electrically conductive materials, such as carbon nanotubes, graphene [16–19] and metal grids [20–23], have been investigated as potential replacements for ITO.

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Received: 19 September 2022; **Accepted:** 02 December 2022; **Published:** 31 December 2022

DOI: 10.57159/gadl.jcmm.1.2.23016.

When used as flexible TFHs, such materials promise to provide uniform thermal distribution over the heating area and reach higher temperatures at low power [24]. Silver nanowires (AgNWs) have emerged as interesting candidates for the fabrication of TFHs because of their good conductivity, high transparency, and appropriate mechanical qualities [25–27], and there have been reports of TFHs based on AgNWs [28–30]. The reported TFHs were created by depositing AgNWs on the surface of a transparent polymer substrate, such as polyethylene naphthalate (PEN) or polyethylene terephthalate (PET), and as they have low thermal resistance, the fabricated AgNW-based film heaters could only attain a certain temperature. Furthermore, the adhesion between the AgNWs and the substrate was weak, and the AgNW network on these substrates was scratch-resistant and easily detached, resulting in low conductivity and inefficient heat production. Thus, filling the gap in the existing literature, the present study describes the in-situ fabrication of transparent sheet heaters with flexibility (TSHF) comprised of a NaW network embedded in a transparent poly(vinyl alcohol) (PVA) film. The NaW/PVA TSHFs are designed to have a desirable combination of properties such as high glass transition temperature (Tg), mechanical flexibility, visual transparency and a strong bonding force with NaW. The TSHFs made from this composite exhibited a high saturation temperature attainment of up to 96 °C, could be heated quickly at lower operation voltages and had only a slight temperature variation over a long period of heating at a constant voltage.

2 Materials and Method

All reagents used in this study were obtained from E. Merck and included poly(vinyl alcohol) (PVA), sodium tungstate (NaW), acetone, and ethanol. Tetraethoxysilane (TEOS ¿98%) was purchased from Sigma-Aldrich. All reagents and chemicals used were of analytical grade. Under vigorous stirring, 5 g of PVA was dissolved in 80 ml distilled water. For 6 hrs, the temperature was maintained constant at 70 °C. After preparing a homogeneous transparent solution, 0.5 gm of tetra ethyl orthosilicate (TEOS) was added, followed by 3-4 drops of HCl as a catalyst. The solution was stirred and maintained at 70°C for another 6 hrs, and then, after the completion of the reaction, the solution was allowed to cool. A gravimetric ratio of sodium tungstate was added to the mixture and stirred for 1 hr. After pouring the slurry mentioned above onto the thick transparent sheet, as shown in Figure 1, a 5 mm Finolex make pure copper wire was inserted into the cast at a distance of 10 cm from both edges of the film. The dimensions of the film were 10 X 5 cm. Two wires from each copper stripe were connected when the copper wires were stretched beyond the sample length, as illustrated in Figure 1.

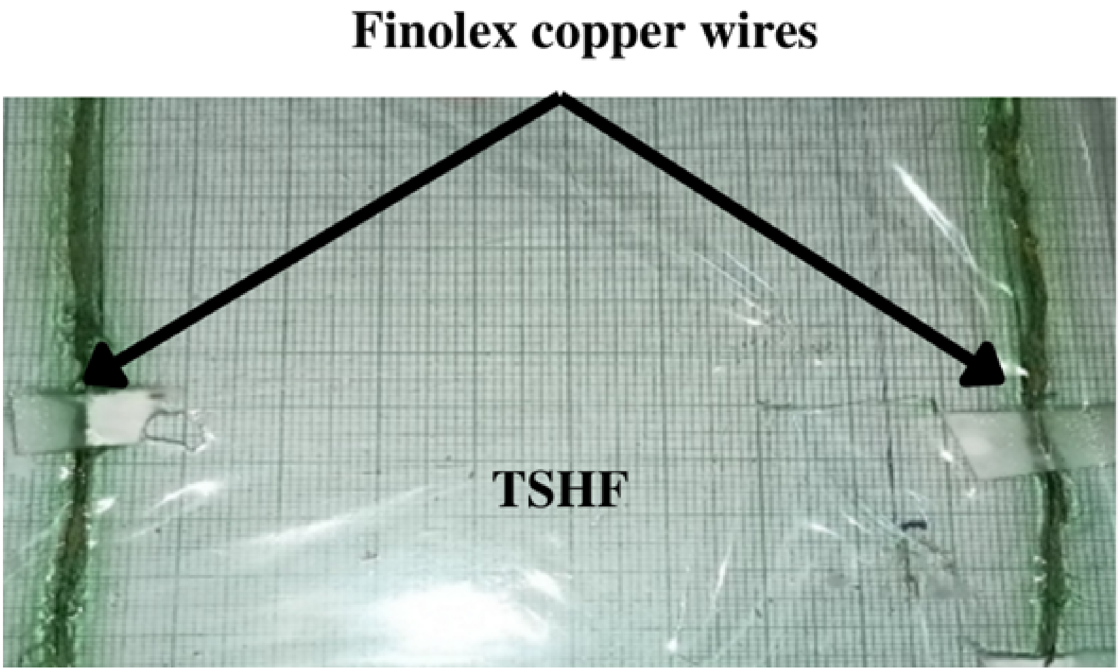

Figure 1: Copper wires attached to the transparent sheet

The concentration and nomenclature of the prepared NaW and PVA films are shown in Table 1. The surface morphologies of NaW/PVA TSHFs were analyzed using scanning electron microscopy (SEM), wherein the SEM images were taken after sputter coating the specimen with gold. The optical transmittance of the transparent PVA film and NaW/PVA TSHFs was measured at room temperature using an ultraviolet-visible spectrophotometer with an integrating sphere, and the sheet resistance of NaW/PVA TSHFs was measured using a four-point probe system. A power source supplied DC voltage to the TSHFs through the copper contact attached at the edge of the film. The temperature of the TSHFs was measured with an infrared thermometer. To accurately reflect the thermal distribution, nine temperature points were measured for each TSHF, and the average value was recorded. Mechanical stability tests were performed using a laboratory-installed bending test machine. The moisture test was carried out using a highly accelerated temperature and humidity stress test (HAST) at a temperature of 120 °C, a relative humidity (RH) of 97% and a gauge pressure of 0.1 MPa. The adhesion test was performed using 3M stock tape.

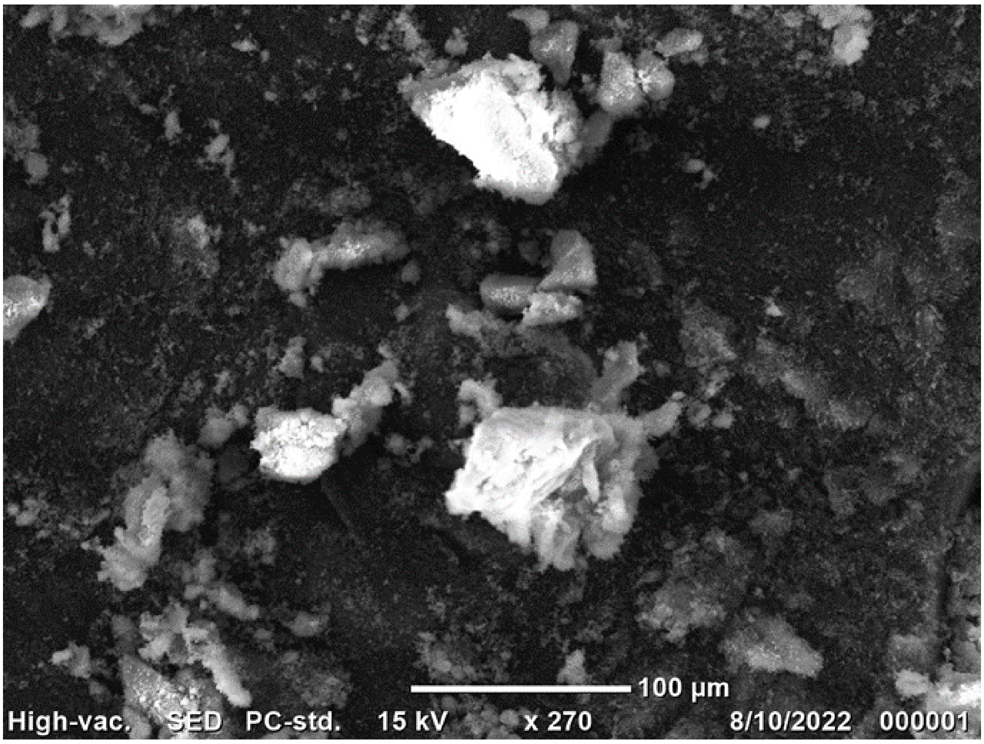

Figure 2: SEM image of the prepared NaW/PVA transparent sheet heater with flexibility.

Table 1: Concentration and nomenclature of the prepared heater films

Sl. No	PVA (g)	Sodium Molybdate (g)	Sodium Molybdate (%)	Film Name
1	5	0.000	0.0	Plain PVA
2	5	0.125	2.5	2.5-NaW/PVA
3	5	0.250	5.0	5-NaW/PVA
4	5	0.375	7.5	7.5-NaW/PVA
5	5	0.500	10.0	10-NaW/PVA

3 Results and Discussion

3.1 Surface morphologies of the prepared NaW/PVA TSHFs

Figure 2 depicts the SEM image of the prepared NaW/PVA TSHF, which exhibits a smooth surface and a well-connected point-to-point junction. The NaW molecules are inlaid on the surface of the films. There were no voids on the surface. Thus, it indicates that all NaW has been transferred to the surface of the PVA film. The surface morphology indicates that the transparent PVA solution thoroughly permeated the NaW network and filled network holes and voids at the interface of the NaW and the rigid substrate.

3.2 Optical and electrical properties of the prepared NaW/PVA TSHFs

Fig 3 depicts the optical transmittance spectra of the TSHFs with increasing refractive index (N). Each TSHF's sheet resistance values are also provided. At 550 nm, the pure PVA film demonstrated a high optical transmittance of 92%. The transmittance of TSHFs decreased as the number of N increased after the NaWs were inserted. The light reflection and scattering from the NaWs caused this change. Furthermore, as N increased, the sheet resistance of the TSHFs decreased. The sheet resistance of the 3NaW/PVA (N=3) sample was 10×10^{-3} Ohm/sq with a transmittance of 83% at 550 nm, whereas the sheet resistance of the 12AgNW/PI (N = 12) sample was 5.6 Ohm/sq with a transmittance of 58% at 550 nm. The findings suggested that the NaW density could be tweaked to improve the optical and electrical properties of NaW/PVA TSHFs.

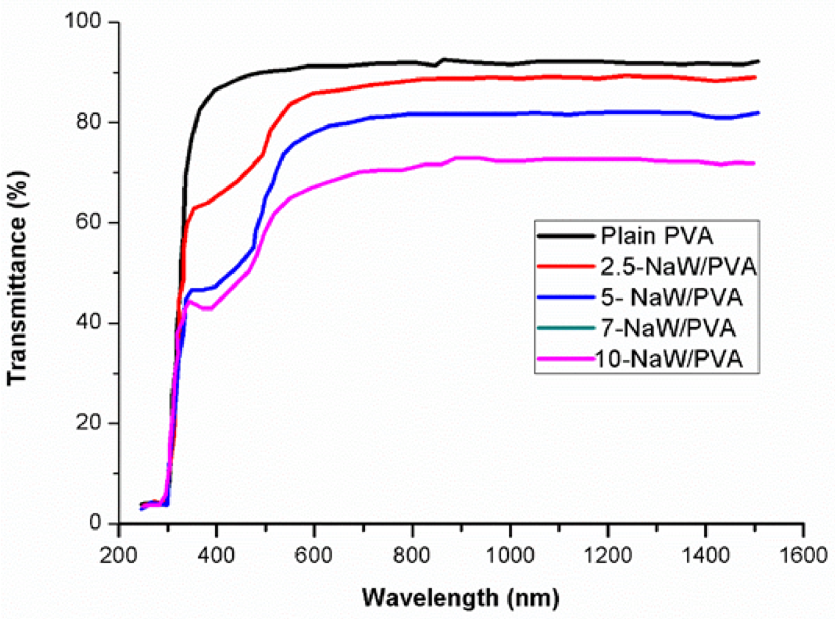

Figure 3: Optical transmittance spectra of the plain PVA film, TSHFs, and the sheet resistance of TSHFs.

3.3 Thermal response behavior of the prepared NaW/PVA TSHFs

The temperature properties of NaW/PVA TSHFs were investigated to better understand the nature of Joule heating in TSHFs. Figure 4 depicts the recorded temperature measurements graphically. The NaW/PVA TSHFs used in this section were 2.5 cm × 2.5 cm in size. Figure 4 depicts the temperature profiles of the TSHFs as a function of input voltage (modulated from 1 to 6 V). The TSHFs used had an optoelectronic performance of 5.6 Ohm/sq and a transmittance of 58% at 550 nm. When the input voltage was set to 1 V, all the plots showed that the temperature of the TSHFs reached 30 °C. The temperature of the TSHFs reached above 96 °C when the input voltage was increased to 6 V, confirming its good operation at a low input voltage. Higher power at a low input voltage implies efficient electrical energy conversion to Joule heating. One of the key factors for evaluating the performance of TSHFs is the response time, which is defined as the time required to reach the steady-state temperature ($T_{\text{steady-state}}$) from room temperature (T_{room}). Regardless of the applied voltage, the temperature increased quickly, and steady-state temperatures were reached in less than 40 sec, demonstrating the device's quick response. Power consumption, defined as temperature increase per unit of electrical power input, is another important parameter for assessing heat performance, which was investigated in the present work by applying Joule's law to the heat generated by a film heater using Eq. [1].

$$P = \frac{U^2}{R} \tag{1}$$

where P is the applied voltage, U is the input power, and R is the resistance of the film heater to which the voltage is applied. Figure 4 indicates the input power of the NaW/PVA TSHFs as a function of steady-state temperature and the input power as a function of steady-state temperature. Based on the data analyzed and the size of the TSHFs, the electrical power consumption of the TSHFs was calculated and found to be around 162 °C cm^{2}W^{-1}.

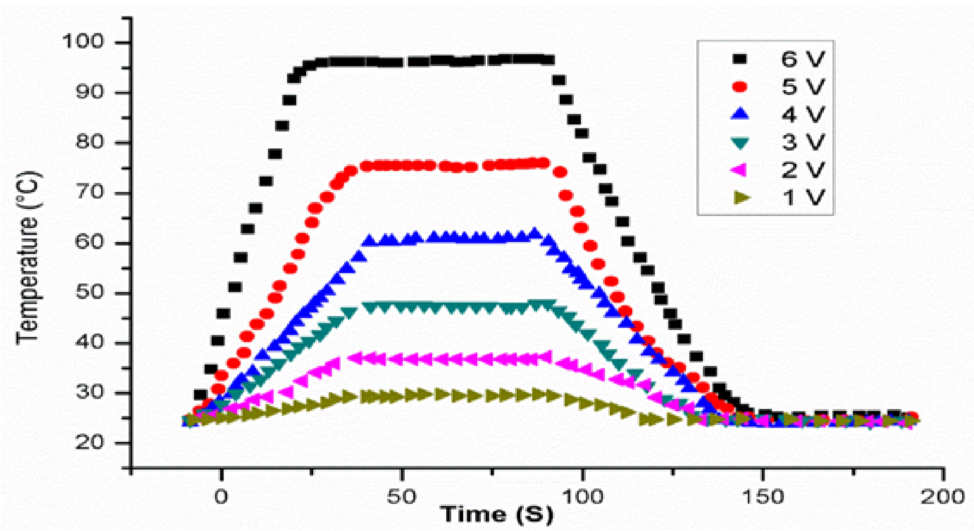

Figure 4: Temperature profiles of NaW/PVA TSHFs as a function of input voltage.

It was observed further that the temperature-time curves remained unchanged while the maximum temperature increased slightly, as seen in Figure 5. Stability tests at an applied bias for 1 hour revealed no significant degradation in achievable temperature, demonstrating the stability for repeated and long-term use. The slight increase in maximum temperature shown in Figure 5 suggested that a slight decrease in heater resistance could be attributed to more tightly connected nanowires. To investigate the thermal response of the NaW/PVA TSHFs that were created, the relationship between the $T_{\text{steady-state}}$ and T_{room} of the NaW/PVA TSHFs is expressed using Eq.[2].

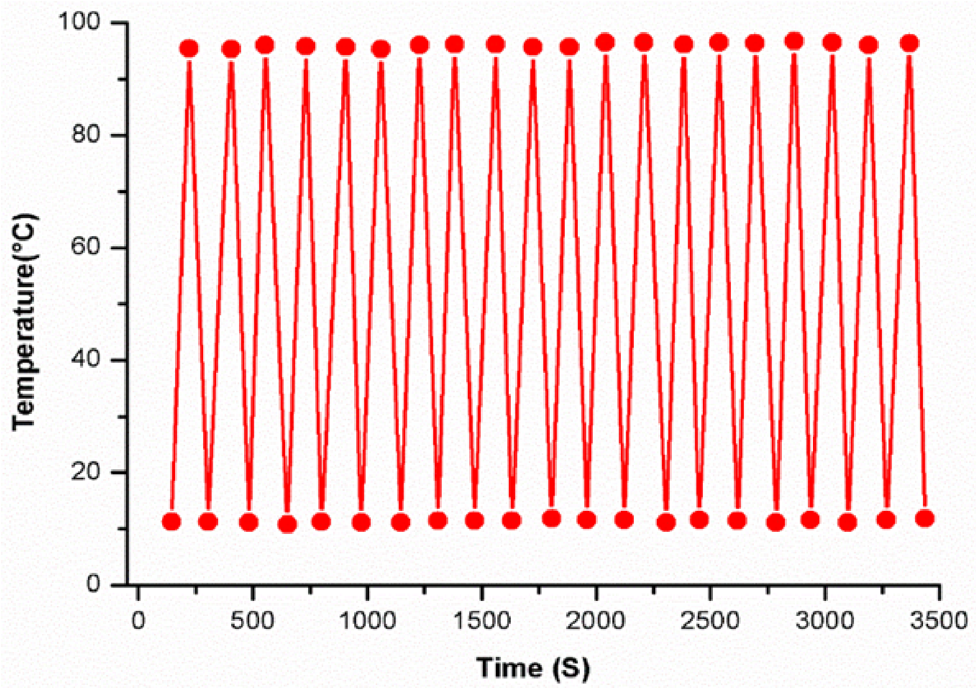

Figure 5: Cycling performance of AgNW/PVA TSFH with a sheet resistance of 5.6 Ohm/sq.

$$T_{\text{steady-state}} = \left(\frac{U^2}{R} - Q_d\right)\frac{1}{C_m} + T_{\text{room}} \tag{2}$$

where C is the heat capacity ratio of the film, m is the film mass, and Q_d is the heat dissipated from the film. Heat dissipation is the transfer of heat by radiation and convection. At temperatures below 150 °C, radiation was found to be negligible. The significant path of heat dissipation was through air convection, and $T_{\text{steady-state}}$ could be attained when Joule heating and convection reach a dynamic balance at elevated temperatures. When the sample geometry is fixed, Eq. (2) shows that $T_{\text{steady-state}}$ increases with increasing voltage U and decreases with decreasing resistance R, or the sheet resistance of the film heater. The maximum temperature at steady state increased as the sheet resistance of the NaW/PVA TSFHs decreased under the same input voltage (6 V), implying that the sheet resistance value of the film should be less than 60 Ohm sq^{-1} to allow for a maximum temperature above 72 °C.

3.4 Mechanical behavior of the prepared NaW/PVA TSFHs

Aside from having excellent surface morphology and thermal response behavior, the prepared NaW/PVA TSFHs exhibited superior mechanical flexibility, which is desirable for emerging flexible electronic devices. Outer and inner bending tests were carried out on a lab-installed bending test system with a fixed bending radius of 5 mm that was controlled as a function of the number of bending cycles. The nominal bending strain was determined using Eq.[3].

$$\epsilon_f = \frac{h}{2r} \tag{3}$$

Figure 6 depicts the change in sheet resistance in the prepared TSFHs. $R = \frac{(R-R_0)}{R_0}$ represents the change in film resistance, where R_0 is the initial sheet resistance and R is the value measured after the bending test. The resistance changes were recorded three times for each bending cycle to ensure measurement accuracy. The resistance changes in the outer and inner bending tests were determined as 0.17% and 0.312%, respectively. Because of the strong bonding between the transparent PVA film and the NaWs network, the electrical properties of the prepared TSFHs were more resistant to outer and inner bending. Under extreme bending, such a strong bond prevents sliding at the interface. Furthermore, a change in the sheet resistance of the prepared TSFHs under extreme folding and crumpling conditions was also observed.

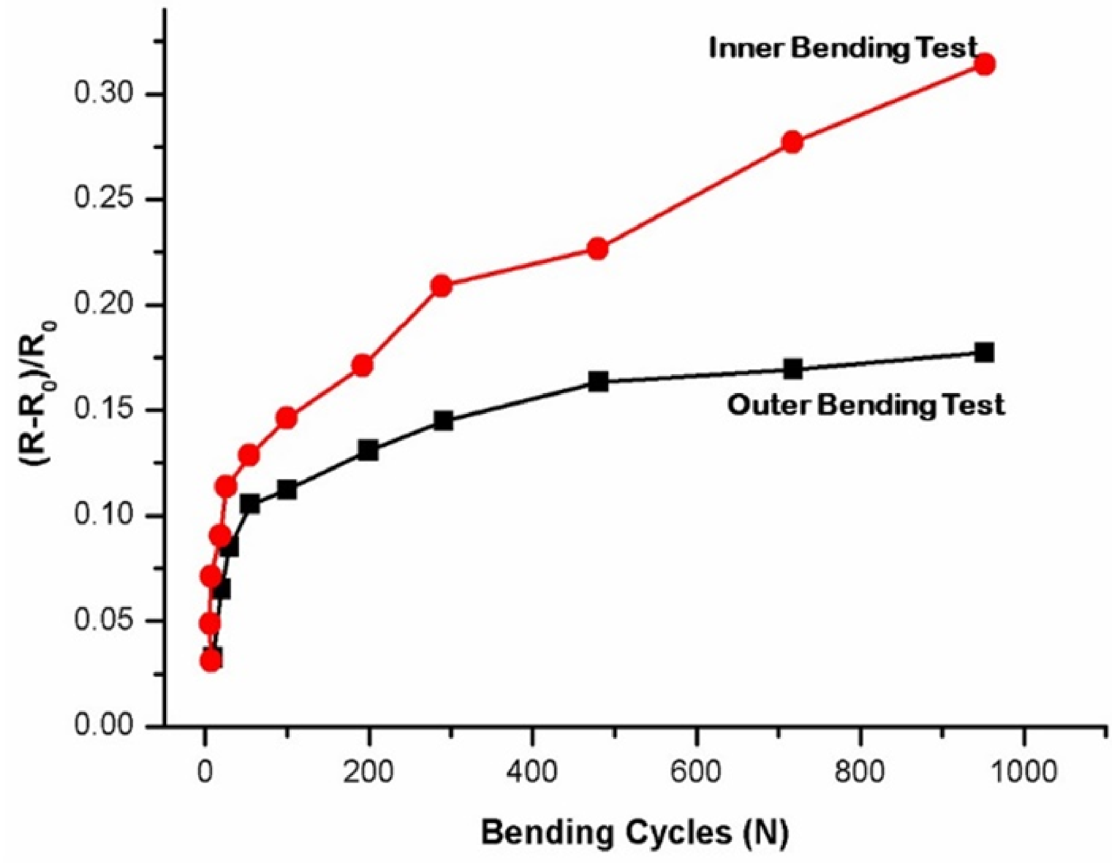

Figure 6: Sheet resistance change of the NaW/PVA TSFHs.

3.5 Moisture behavior of the prepared NaW/PVA TSFHs

The optical and electrical performances of prepared TSFHs were evaluated in a humidity chamber (122 °C, 97% relative humidity for 24 hrs) for thermal moisture testing to confirm long-term reliability. The optical and electrical properties of the prepared TSFHs before and after thermal moisture testing are shown in Figure 7(a). The change in the PVA film in the harsh environment caused a slight decrease in transmittance (T_{550}, before = 64.0% and T_{550}, after = 61.0%). The resistance increase was primarily caused by the oxidation of a small amount of NaWs exposed on the surface of the prepared NaW/PVA TSFHs. The thermal response of the NaW/PVA TSFHs before and after thermal moisture testing is depicted in Figure 7(b). $T_{\text{steady-state}}$ dropped from 76 °C to 74 °C. Because of the nearly stable heating temperature, the prepared TSFHs can be used in defrosting window panels applications in outdoor advertisement boards. The TSFHs' adhesion was tested by repeatedly sticking and peeling them. On the surface of the TSFHs, 3M Scotch tape was applied. The sheet resistance increased by only 0.057 after 1000 adhesion peeling cycles, indicating a strong bonding of the conductive nanowires on the TSFHs.

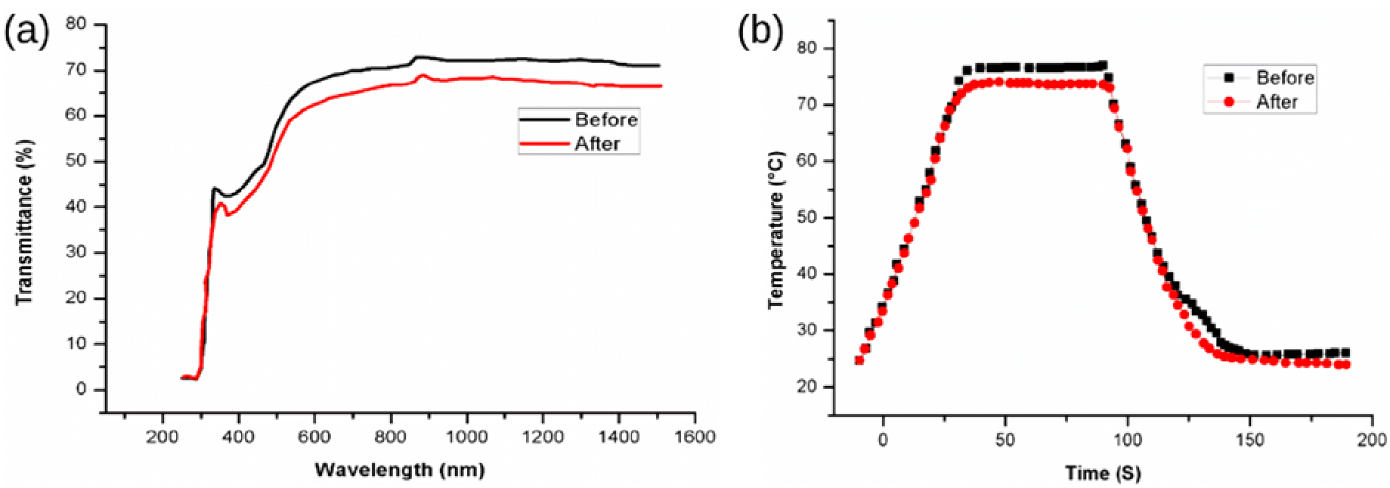

Figure 7: **(a)** Optical and electrical properties of the prepared TSFHs before and after thermal moisture testing, and **(b)** Thermal response of the NaW/PVA TSFHs before and after thermal moisture testing.

4 Conclusion

A solution process was used to create flexible TSFHs with a NaWs network embedded in the surface of a transparent PVA film. A typical NaW/PVA TSFH with a low sheet resistance of 5.6 Ohm/sq and a transmittance of 58.0% were obtained by adjusting the number of rod-coating cycles of the NaW suspension. Thermal response tests on NaW/PVA TSFHs revealed a higher heating temperature of 97 °C, a fast response time of less than 40 sec, and lower power consumption of 161.2 °C cm^2W^{-1}, as well as repeatability. NaW/PVA TSFH mechanical properties were also investigated. The resistance changes in the outer and inner bending tests were 0.18% and 0.31%, respectively. Furthermore, after 24 hours of testing in a humidity chamber at 122 °C/97% relative humidity, the NaW/PVA TSFHs demonstrated nearly stable optical properties, sheet resistance, and heating temperatures. As a result, the fabricated NaW/PVA TSFHs may find use in window defogging, thermochromic, and transparent electrodes.

Declaration of Competing Interests

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding Declaration

This work was supported by the Vision Group for Science and Technology (VGST), Govt. of Karnataka, Bengaluru, India, under grant number GRD No: 951 (2020–2021) for establishing the laboratory at Basaveshwar Science College, Bagalkot, India.

Author Contribution

Deepa Joshi: Conceptualization, Methodology; **Aboobakar Savanur**: Data curation, Writing- Original draft preparation; **Laxmibai Rathod**: Visualization, Investigation; **Mallikarjunagouda Patil**: Supervision, Reviewing and Editing, Validation; **Arun Y Patil**: Writing- Reviewing; S N Mathad: Writing- Reviewing.

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Volume 1 Issue 2

CLEAROSO: A Cleaning Robot for the Solar Panels

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Abstract

Non-renewable power sources being sustainable have a major impact on controlling global warming. Solar energy is one of the prominent non-renewable energy sources that has been increasingly utilized in recent years to generate solar power using solar panels. The accumulation of dust (also known as soiling) on the surface of solar panels reduces the quantity of sunlight reaching the solar cells beneath, lowering the efficiency of the solar panel. To fully utilize their specified capacity, they must be cleaned regularly, often with water. Cleaning solar panels, especially when large in numbers, consumes much time. The cleaning of solar panels has become complex, complicated, and ultimately costly due to the growing water shortage problem in most parts of the world. The current study also suggests the development of a solar panel cleaning robot to address the issues connected with the traditional technique of solar panel cleaning. In the present work, an appropriate methodology was developed to balance the robot on the solar panel, having the ability to clean the panels with no wastage of water and no damage to the panels. Since the proposed cleaning process is automated, cleaning time was significantly reduced, and the usage of water and the effort of the personnel was eliminated. Several cleaning trials were conducted using the robot, and the result indicated an increase in the overall efficiency of the solar panel cleaning process.

Keywords: Photovoltaic Panel Cleaning; Sensors; Robotics; Water-Free Cleaning; Real-Time Systems

1 Introduction

Solving today's environmental issues necessitates long-term prospective initiatives for sustainable development, and renewable energy (RE) resources appear to be among the most efficient and effective alternatives in this respect [1]. Global and regional trends imply that renewable energy sources will soon meet most global energy demands [2]. In other words, RE is predicted to alleviate energy crises by playing a critical role in satisfying future power demands [3]. Solar and wind energy are the most promising and effective renewable energy sources, encouraging interest in expanding their use globally [4, 5]. Global solar energy output is predicted to grow faster than any other energy source until the middle of the century, particularly in locations with high levels of dust and/or anthropogenic particle pollution, such as major portions of India, China, and the Arabian Peninsula [6]. India's RE potential is around 900 GW from diverse sources, with solar power contributing 83% and hence is the major contributor [7]. Photovoltaic (PV) energy production through PV panels is one of the most promising and mature renewable energy production technologies [8]. PV panels are composed of several cells linked together to create power at the correct voltage. Photovoltaic panels are essentially direct current (DC) devices. They are used in conjunction with an inverter to generate alternating current (AC) [9]. Photovoltaic cells or solar cells are diodes that convert sunlight directly into electricity and have a wide surface area exposed to the sun.

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Received: 14 September 2022; **Accepted:** 17 December 2022; **Published:** 31 December 2022

DOI: 10.57159/gadl.jcmm.1.2.23013.

The performance of a PV cell is affected by irradiance (the radiant flux received by a surface per unit area), light spectrum, and cell temperature. The maximum current rises in proportion to the rising irradiance, improving cell performance. For a known value of voltage (V) and current (I), the efficiency of cells with an area (A) at irradiance (G) is expressed by Eq. [1]. The irradiance considered for the calculation of the efficiency of a PV solar cell is considered as 1000 W/m2, as per the standard test condition (STC) [10]. There exist varieties of solar PV cells, but the crystalline silicon (c-Si) solar cell accounts for 80% of the global market [11–13].

$$\eta = \frac{VI}{AG} \tag{1}$$

Solar panels absorb solar energy and effectively generate electrical output. However, environmental conditions impact and influence electrical output energy [14]. Dust deposition is one of the environmental elements that have a major impact on the efficiency of solar modules [15–17]. Dust (visible, unseen, floating and falling solid particles) is estimated to reduce electricity output by around 1 and 11 GW in India and China, respectively. Here, ”dust” refers to minute, crushed particles less than 500 µm in size that enter the atmosphere from various sources, including industrial facilities, construction sites, and dust storms [18]. When sunlight strikes the surface of the PV modules, it activates them; consequently, when dust particles accumulate on the panel, the area that transmits photons reduces, preventing light energy from reaching the PV cells. This problem may be prevented by planning and implementing an efficient cleaning system [19], [20]. Manual cleaning, vacuum suction cleaning, automatic wiper-based cleaning, and electrostatic precipitator-based cleaning are some of the most often used PV panel cleaning methods. The first two are the most traditional and frequently used cleaning methods requiring active human intervention [21]. Various scholars have sought to tackle dust buildup issues and enhance the efficiency of solar panels while reducing human intervention through various designs and methods, particularly by designing automated robots.

For example, Krauter [22] developed a robotic device that used a silicone rubber foam brush to clean PV modules more efficiently. Demain et al. [23] devised an autonomous self-cleaning mechanism based on components such as light-dependent resistor (LDR) sensors, sprayers, and wiper units controlled by solar panels' output. Sera and Baghzouz [24] devised an alternate method by cleaning the panel surface using a brush embedded in disk equipment with a polymer tip. Swain et al. [25] created a self-powered solar panel cleaning mechanism that uses a brush operated by direct current (DC) motors and an Arduino microprocessor to clean the SPV panel. Chailoet and Pengwang [26] created a solar panel cleaning robot using a spiral brush and a rubber sweeper. Ghodki [27] created an infrared-based dust mitigation device controlled by a robotic arm. Ronnaronglit and Maneerat [28] created a solar panel cleaning robot that uses a gear motor and an Arduino microprocessor. Kumar et al. [29] created a self-powered robot remotely controlled by the Internet of Things (IoT) to clean the panel surface and reduce the need for human intervention.

Using the previous study as inspiration, the current work aims to integrate multiple technologies, including a DC motor, an infrared system, a Bluetooth system, and an Arduino microprocessor, to create a solar panel cleaning robot (CLEAROSO). Furthermore, the difficulty in regulating CLEAROSO's movement was addressed using specifically constructed frame-calibrated motions. After cleaning a given region, the developed robot proceeds autonomously to the next uncleaned portion of the panel, eliminating the need for human intervention throughout the cleaning process.

2 Materials and Methods

2.1 System overview

As seen in Fig. 1 (a), the CLEAROSO block diagram comprises an input, processor, and output components. The robot's primary element is the input mechanism, comprising one traditional manually controlled switch unit and two infrared (IR) sensors. The action of the rollers and sliders was controlled by infrared sensors that were positioned in such a manner that they recognized the position of each panel using position objects (or stoppers) attached to the bottom. Panel positioning was accomplished by the use of stoppers that reflect IR radiation. The input data and information were passed to the second element, a processor (type Arduino - ATmega328P microcontroller) integrated using the Arduino IDE. The last element is the output source, comprising a DC motor for controlling robot movement and a Bluetooth module integrated with Android apps for testing voltage and current levels. Figure 1 (b) depicts the hardware connections. A mechanical frame that moved right and left and reached all display regions was employed to increase performance. The robot was intended to move in linear motion during the cleaning procedure. A short-term cleaning mechanism was used to complete the operation as quickly as possible. Due to Bluetooth limitations, the optimal functioning range for CLEAROSO was determined to be 20 meters. Each hardware component's desired functionality was achieved using Bluetooth modules and gear motors. The Bluetooth module was connected to Arduino Uno and successfully accepted signals from the android application. Later, the processed signal was sent to the microcontroller. The gear motor received the signals from the Bluetooth module through the microcontroller. The user input sent through the Bluetooth module moved the motor forward and backward. The various components used in making CLEAROSO are given in Table 1. The infrared sensor, once activated, began to measure the robot's movement distance. For the robot's movement distance of less than 4 cm, it was programmed to continue to move forward, and for a distance exceeding 4 cm, the robot was programmed to move backward. Once the time delay set in the microcontroller reached 1000 ms, the robot was programmed to stop moving in the backward direction and resume moving in a straight line. The described movement tends to repeat until the robot is shut down.

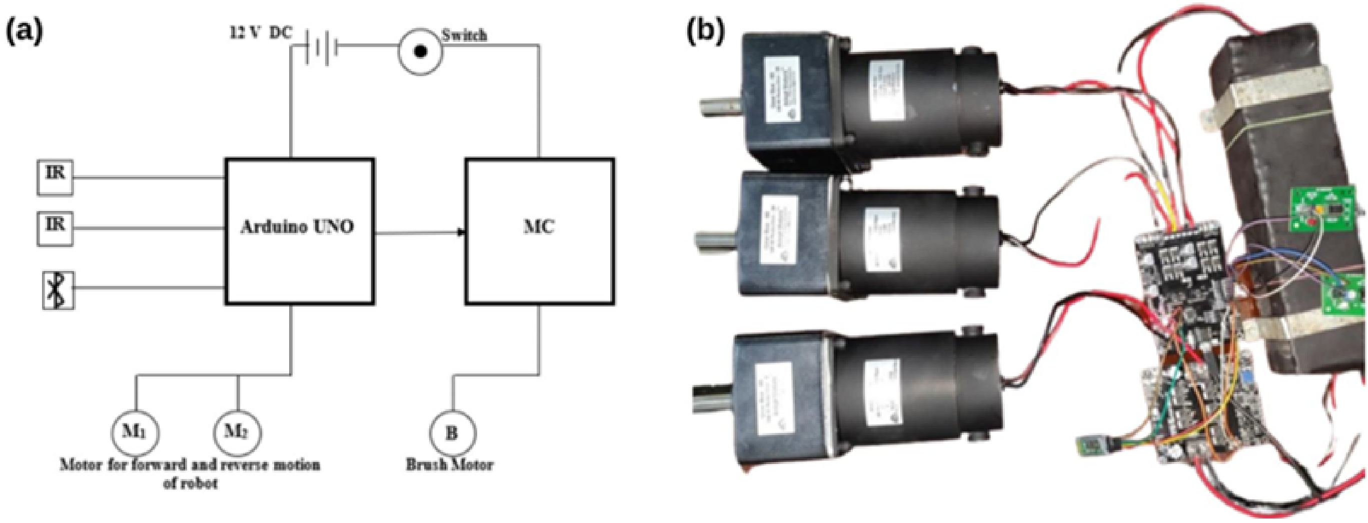

Figure 1: CLEAROSO System: **(a)** Block diagram;**(b)** motor connections to the main circuit.

Component	**Type**	**Technical specifications**
Arduino Uno	Microcontroller	ATmega328P Weight of 25 grams Length of 68.6 mm Width of 53.4 mm
Infrared (IR) sensor	Sensor	Magnetic sensor
Stepper Motor	DC Motor	24 V Gear Motor Torque: 173 kg-cm Rotational speed: 15 RPM Power output: 30 W
Bluetooth Module	Serial Communication Device	TX / RX Pin
Arduino Software (IDE)	Software	Arduino programming language (based on wiring)
Solar panel	Prototype (miniature version)	Length = 100 cm Width = 60 cm

Table 1: Hardware and software list

3 Solar panel characteristics

Several experiments were conducted to clean a dirty solar panel to assess the efficiency of the developed solar panel cleaning robot (CLEAROSO). In these experiments, fine sawdust was utilized to simulate solar panel dust. For the experimental procedure, the current and voltage of undusted, dusty and cleaned solar panels were measured every hour, starting from 12.00 pm until 3.00 pm. Since the area of the PV solar cell prototype was already known, the power was determined by measuring the voltage and current for the solar panel prototype in its dusty condition and after dust removal. Afterward, the efficiency, η was calculated using Eq. [1].

4 Results and Discussion

The developed robot was coded to move in a straight line, forward and backward, because it was tested on a small solar panel. Suppose the developed robot is planned to be tested on a larger array of solar panels. In that case, the robot's movement can be coded as per proper walking path to efficiently clean all the solar panels. Table 2 summarizes the measured data, calculated power and solar panel efficiency obtained using Eq. [1]. From the results obtained after the dust-removal process, the power and solar panel efficiency have increased by an average value of 53.65%. The increase in efficiency proves the developed robot's effectiveness and workability. Moreover, compared to traditional solar cell cleaners, CLEAROSO proved to be a better option as the cleaning time got halved, and the usage of water and human intervention was eliminated. The efficiency can further be increased by modifying the cleaning mechanism and improving the kinematics of the proposed model, and thus can be considered a possible extension to the presented work. The investigation of speed and work efficiency at an angular-positioned solar panel can also be considered a future scope of the presented work.

Table 2: Hardware and software list.

Time	Dusty panel		Clean panel		Power (W)		Efficiency (%)
	Voltage (V)	Current (A)	Voltage (V)	Current (A)	Dusty Panel	Clean panel	
12.00 pm	20.27	0.076	20.27	0.146	1.54	2.96	49.32
01.00 pm	20.22	0.097	20.22	0.152	1.96	3.07	51.22
02.00 pm	22.31	0.094	22.31	0.151	2.10	3.37	56.15
03.00 pm	23.28	0.083	23.28	0.149	1.93	3.47	57.81

5 Conclusion

This paper describes the development of a fully assembled solar panel cleaning robot. The Arduino platform is used to develop the control algorithm and cleaning sequence. The robot is powered entirely by rechargeable batteries, and the movements are obtained using motors. The efficiency of the robot working was quantified using the power output by the solar panel prototype. After cleaning, the solar panel generated more than 50% of its power. The increased power output demonstrates the developed CLEAROSO robot's efficient workability.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding Declaration

This research did not receive any grants from governmental, private, or nonprofit funding bodies.

Author Contribution

Nikheel N. Deshmukh: Conceptualization, Visualization, Investigation Methodology, Data curation, Writing- Reviewing; **Devendra Chitale**: Supervision, Writing- Reviewing; **Raghavendra C. Kamath**: Supervision, Writing- Original draft preparation, Writing- Reviewing.

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Volume 1 Issue 2

SASHAKT: A Job Portal for Women using Text Extraction and Text Summarization

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Abstract

SASHAKT is a job portal designed specifically for women, utilizing text extraction and summarization techniques to provide a user-friendly and efficient job search experience. The portal extracts relevant information from job postings and summarizes it, allowing women to quickly identify job opportunities that align with their skills and qualifications. Additionally, the portal utilizes text classification algorithms to identify and filter out job postings that may be discriminatory or biased toward women. This study presents the development and implementation of SASHAKT, including a detailed description of the text extraction and summarization techniques used and the text classification algorithms implemented to detect discriminatory language. The study also presents the results of user testing and evaluations of SASHAKT, highlighting its effectiveness in improving the job search experience for women. The results of this study demonstrate that SASHAKT can help increase women's representation in the workforce by providing them with a more efficient way to find job opportunities that align with their skills and qualifications. Furthermore, the study also highlights the potential for similar text-based approaches to be applied to other areas of job search and career development for underrepresented groups such as people with disabilities and minority groups. Overall, the study concludes that SASHAKT is an innovative solution that addresses the need for a more inclusive job search experience for women by utilizing natural language processing techniques.

Keywords: Text Summarization; Text Extraction; Text Localization; Text Detection; Natural Language Processing

1 Introduction

The job search process can be challenging and time-consuming for many individuals, particularly women, who may face discrimination and bias in the workforce. Women are underrepresented in many industries and often face barriers to career advancement. According to a study by McKinsey, women are less likely to be promoted to management positions and are underrepresented in industries such as technology, finance, and manufacturing [1–4]. In the last twenty-five years, India has experienced significant socioeconomic transformation. India has experienced rapid economic growth, structural economic shifts accompanied by high urbanization rates, increased educational attainment, and declining fertility rates. However, there has been a gradual and persistent decline in women's economic activity [5]. Female economic empowerment and workforce participation are particularly significant issues in India, and the country ranks 139th out of 144 in terms of gender equality in economic participation and opportunity. Gender inclusion in the hiring process is critical because low female labor force participation impedes economic growth. India's gross domestic product (GDP) could increase by 27% if female participation rates matched those of men - and there is evidence that low participation rates are partly caused by discrimination and other hiring barriers. India's female labor force participation rate (FLPR) is low, at 24% overall and 16% in urban areas, placing it 120th out of 131 nations [6]. Even Indian women who have opted to work face difficulties in finding jobs. Involuntary unemployment has a 4.7% point gender disparity (8.7% of working-age women are unemployed, but only 4.0% of comparable men are) [7].

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Received: 06 October 2022; **Accepted:** 17 December 2022; **Published:** 31 December 2022

DOI: 10.57159/gadl.jcmm.1.2.23022.

This disparity is even greater among highly educated urban dwellers, with both groups losing 8.8% points, as shown in Figure 1. The state with the least gender inequality is ranked one, and the state with the highest gender inequality is ranked 15th. Challenges in finding suitable employment partly explain the low labor rate. Women have more difficulty finding jobs than men [8]. While the internet and online recruiting techniques enhance access to work chances for female applicant groups, an increase in the number of applicants might encourage managers to depend more heavily on demographic-based preconceptions, whether purposely or accidentally. This type of prejudice is a global problem, and new and unique remedies to eliminate the bias are required to counteract these tendencies.

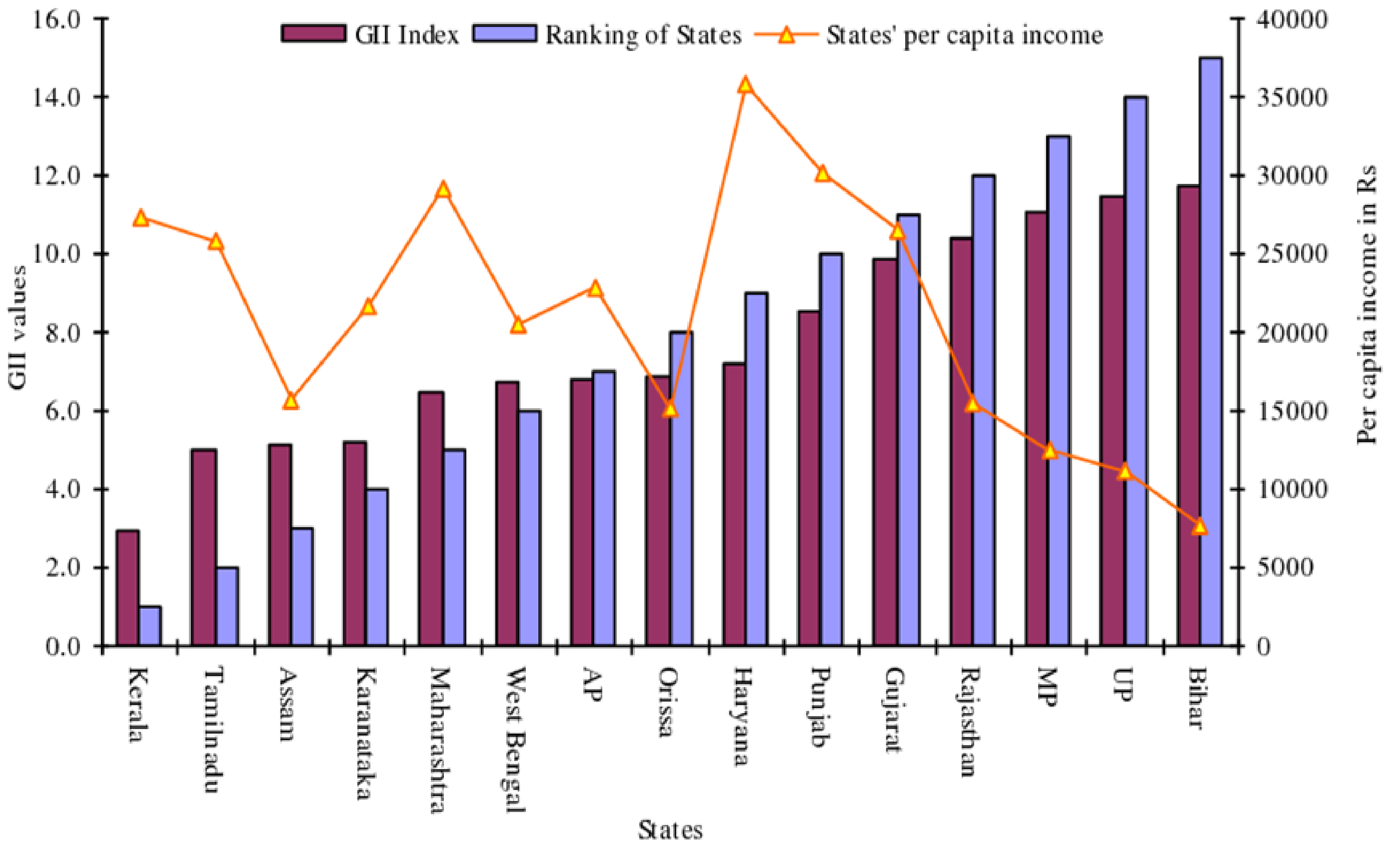


Figure 1: Gender inequality in highly educated urban dwellers

Additionally, a study by LeanIn found that women are often passed over for promotions and are less likely to receive critical stretch assignments that can help them advance in their careers [9, 10]. The job search process can be particularly challenging for women, who may face discrimination and bias in the workforce [11]. According to a study by the National Women's Law Center, women are often subject to gender bias in the hiring process and are less likely to be offered job interviews or receive job offers than men [12]. Additionally, a study by the Center for Talent Innovation found that women are often judged on their perceived potential rather than their qualifications and experience [13]. Such judgments make it difficult for women to advance in their careers and lead to a lack of representation in many industries, thus emphasizing the need for a technique to ease the job application process. Text extraction and summarization techniques are commonly used in natural language processing to extract relevant information from the text and present it in a condensed format. These techniques can extract information from job postings and summarize it concisely, making it easier for job seekers to identify job opportunities that align with their skills and qualifications. Common text extraction and summarization techniques include keyword extraction, named entity recognition, and sentence compression [14–16]. Text classification algorithms are commonly used in natural language processing (NLP) to classify text into different categories or labels. These algorithms can detect discriminatory language in job postings and filter them out [17]. Common text classification algorithms include support vector machines, decision trees, and naive Bayes [18]. Figure 2 represents the block diagram of the discussed text extraction technique, while Figure 3 represents the block diagram of the text summarization technique.

The proposed NLP-based job portal, SASHAKT, extracts relevant information from job postings and summarizes it, allowing women to quickly identify job opportunities that align with their skills and qualifications. Additionally, the portal utilizes text classification algorithms to identify and filter out job postings that may be discriminatory or biased toward women. This approach addresses women's need for a more inclusive job search experience by utilizing natural language processing techniques. The development of SASHAKT involved thoroughly analyzing women's current job search landscape and challenges. The existing job portals were reviewed, and key features that could be improved to better serve women's needs were identified. Text extraction and summarization techniques were then implemented to extract relevant information from job postings and present it concisely. Additionally, text classification algorithms were implemented to detect the discriminatory language in job postings and filter them out.

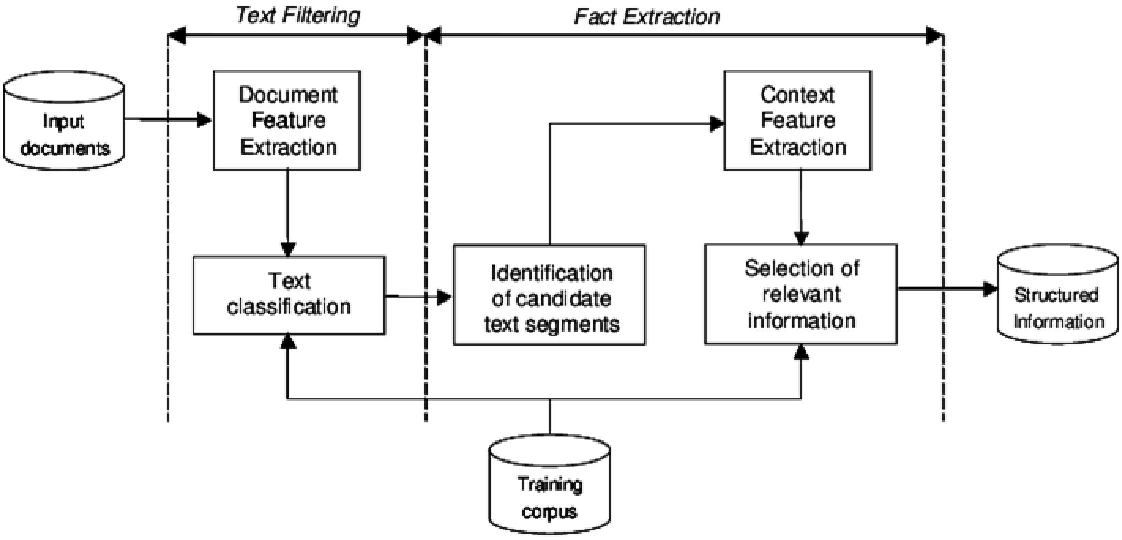


Figure 2: Text extraction block diagram

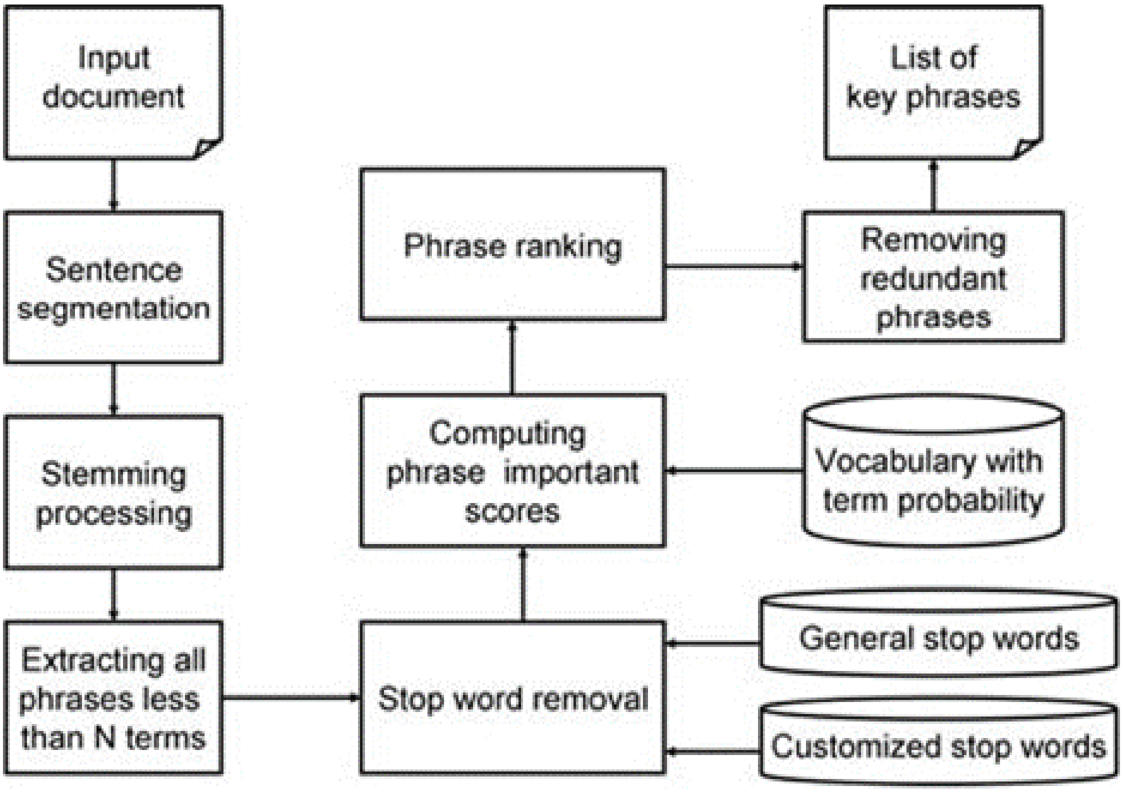


Figure 3: Text summarization block diagram

2 Method

2.1 Development of SASHAKT

SASHAKT is developed to cater to both ends of the recruitment process - recruiters and job seekers. It utilizes a React-based frontend that communicates with the Django backend via REST APIs written using Django Rest Framework (DRF). The data is stored in a SQL/Postgres database hosted on Heroku, while the frontend is hosted on Netlify. Figure 4 shows the hiring mechanism proposed using SASHAKT to create job postings, connect job seekers, and organize them in a single place while streamlining the complete recruitment process using text extraction, summarization, and classification techniques of natural language processing. Figure 5 represents the client-side of the job portal. SASHAKT simplifies data management for registration details such as personal information, contact information, and login credentials through safe storage in a database. The portal operates like any other web application, utilizing a database and REST APIs on the backend server to seamlessly communicate with the program logic and present the desired results to the user, as illustrated in Figure 6.

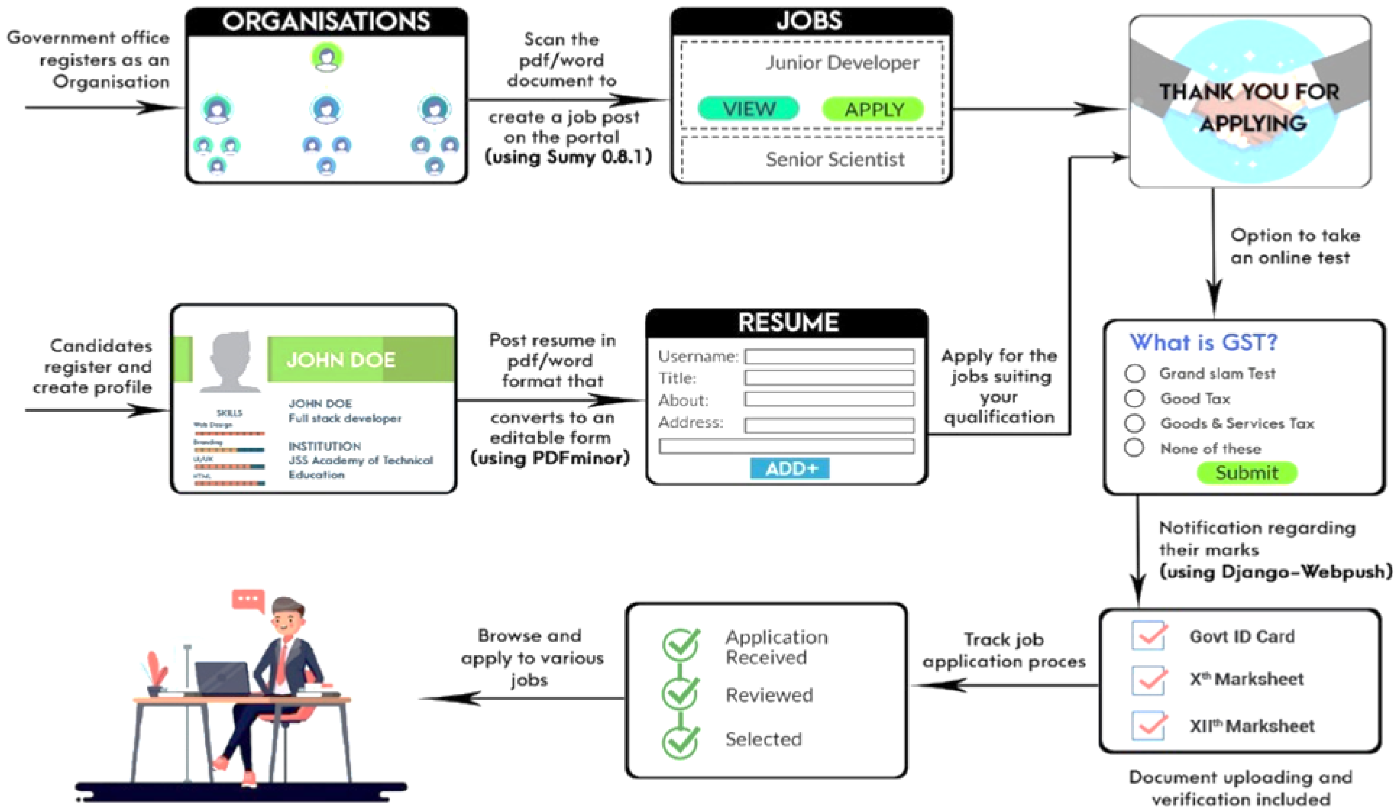


Figure 4: Hiring mechanism through online job portals

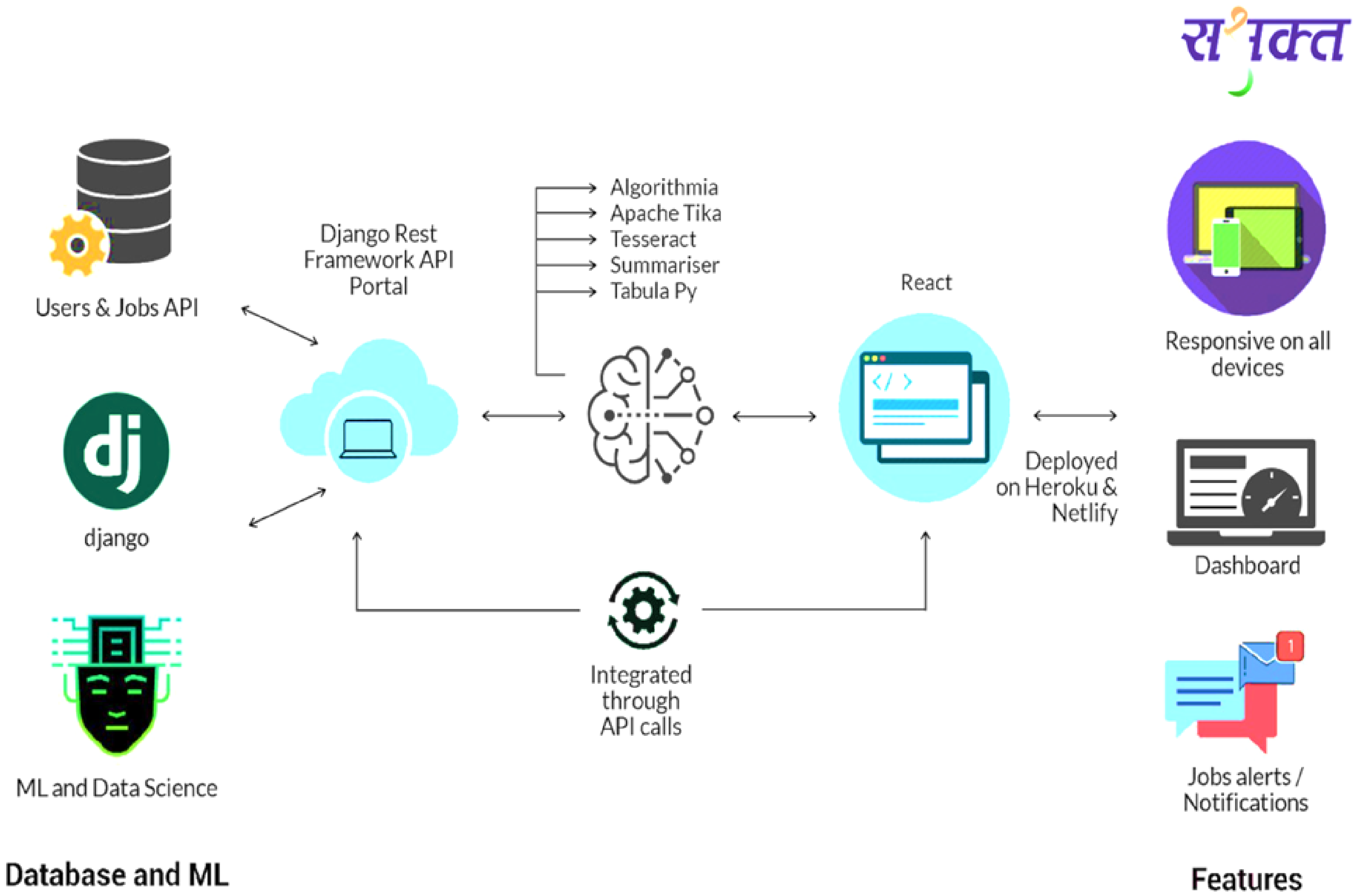


Figure 5: Technology stack for the online job portal

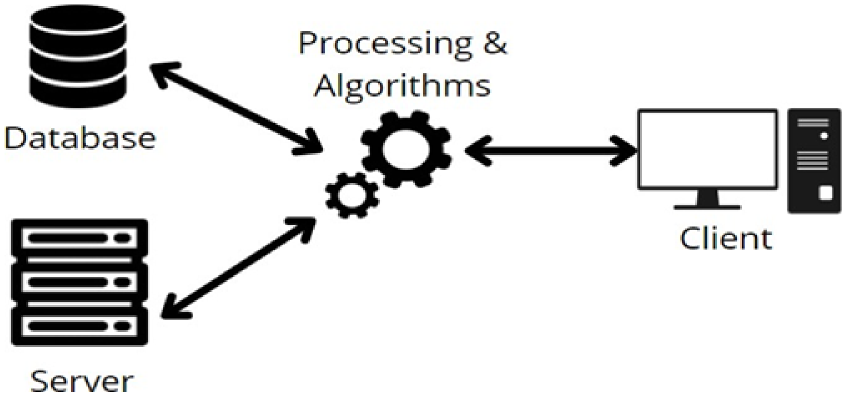


Figure 6: Architecture diagram

The development of SASHAKT involved thoroughly analyzing women's current job search landscape and challenges. The working of the web application can be explained in the following four steps:

1. Step 1: The user uses a web browser or a mobile application to access the web application, which sends a request to the web server via the internet. Security mechanisms such as firewalls or cloud access security brokers and load balancers may be in place.
2. Step 2: The request is forwarded to the web application server via the web server. The web application server completes the required operation, such as accessing the database or processing data, and generates the requested data results.
3. Step 3: The results are returned to the web server by the web application server.
4. Step 4: The web server sends the requested data to the client (desktop, mobile device, and tablet), and it is displayed on the user's screen.

2.2 Text Extraction and Summarization Techniques

The existing job portals were reviewed, and key features that could be improved to better serve women's needs were identified. Text extraction and summarization techniques were then implemented to extract relevant information from job postings and present it in a concise format. The text extraction and summarization techniques used in SASHAKT included keyword extraction and sentence compression. Keyword extraction was used to identify the most important terms and phrases in a job posting, while sentence compression condensed the text into a more concise format.

2.3 Text Classification Algorithm

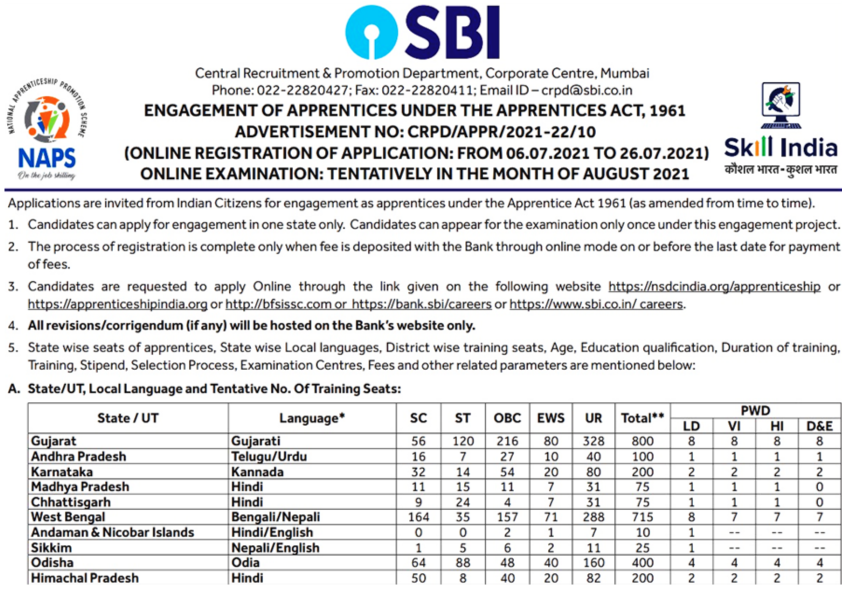
Additionally, text classification algorithms were implemented to detect discriminatory language in job postings and filter them out. The text classification algorithms implemented in SASHAKT include support vector machines and naive Bayes. These algorithms were trained on a dataset of job postings and were used to detect the discriminatory language in job postings and filter them out.

2.4 User Testing and Evaluations

The effectiveness of SASHAKT was evaluated through user testing and evaluations. Participants were asked to search for job opportunities using SASHAKT and provide feedback on their experience. The evaluations included questions about the usability of the interface, the effectiveness of the text summarization feature, and the accuracy of the text classification algorithms.

3 Results and Discussion

Figure 7 represents a sample Portable Document Format (PDF) advertising the job call for an apprentice post in the State Bank of India, which was added to the system to extract information. The goal was to obtain basic information about the job and list it on the portal. The main objective was to test the functionality of the proposed text extraction algorithm-based job portal and see how the job details are displayed in a summarized form. Figure 8 represents the result obtained for the uploaded PDF. The basic information from the PDF is extracted from the uploaded form, as shown in Figure 8, and it has automatically updated the job creation form. This listing can be posted like any other job on the portal; every eligible candidate can see it and apply for it if interested. However, during the development process, some drawbacks were identified. The time taken for the extraction and summarization process was determined to be dependent on the algorithm used by the library. In some cases, not all data from the PDF were extracted properly, so manual input was required.



SBI

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ENGAGEMENT OF APPRENTICES UNDER THE APPRENTICES ACT, 1961
ADVERTISEMENT NO: CRPD/APPR/2021-22/10
(ONLINE REGISTRATION OF APPLICATION: FROM 06.07.2021 TO 26.07.2021)
ONLINE EXAMINATION: TENTATIVELY IN THE MONTH OF AUGUST 2021

NAPS
Skill India

Applications are invited from Indian Citizens for engagement as apprentices under the Apprentice Act 1961 (as amended from time to time).

1. Candidates can apply for engagement in one state only. Candidates can appear for the examination only once under this engagement project.
2. The process of registration is complete only when fee is deposited with the Bank through online mode on or before the last date for payment of fees.
3. Candidates are requested to apply Online through the link given on the following website https://nsdcindia.org/apprenticeship or https://apprenticeshipindia.org or http://bfsissc.com or https://bank.sbi/careers or https://www.sbi.co.in/ careers.
4. **All revisions/corrigendum (if any) will be hosted on the Bank's website only.**
5. State wise seats of apprentices, State wise Local languages, District wise training seats, Age, Education qualification, Duration of training, Training, Stipend, Selection Process, Examination Centres, Fees and other related parameters are mentioned below:

A. State/UT, Local Language and Tentative No. Of Training Seats:

State / UT	Language*	SC	ST	OBC	EWS	UR	Total**	PWD			
								LD	VI	HI	D&E
Gujarat	Gujarati	56	120	216	80	328	800	8	8	8	8
Andhra Pradesh	Telugu/Urdu	16	7	27	10	40	100	1	1	1	1
Karnataka	Kannada	32	14	54	20	80	200	2	2	2	2
Madhya Pradesh	Hindi	11	15	11	7	31	75	1	1	1	0
Chhattisgarh	Hindi	9	24	4	7	31	75	1	1	1	0
West Bengal	Bengali/Nepali	164	35	157	71	288	715	8	7	7	7
Andaman & Nicobar Islands	Hindi/English	0	0	2	1	7	10	1	--	--	--
Sikkim	Nepali/English	1	5	6	2	11	25	1	--	--	--
Odisha	Odia	64	88	48	40	160	400	4	4	4	4
Himachal Pradesh	Hindi	50	8	40	20	82	200	2	2	2	2

Figure 7: Sample PDF uploaded to the system for the job posting of Apprentice at the State Bank of India

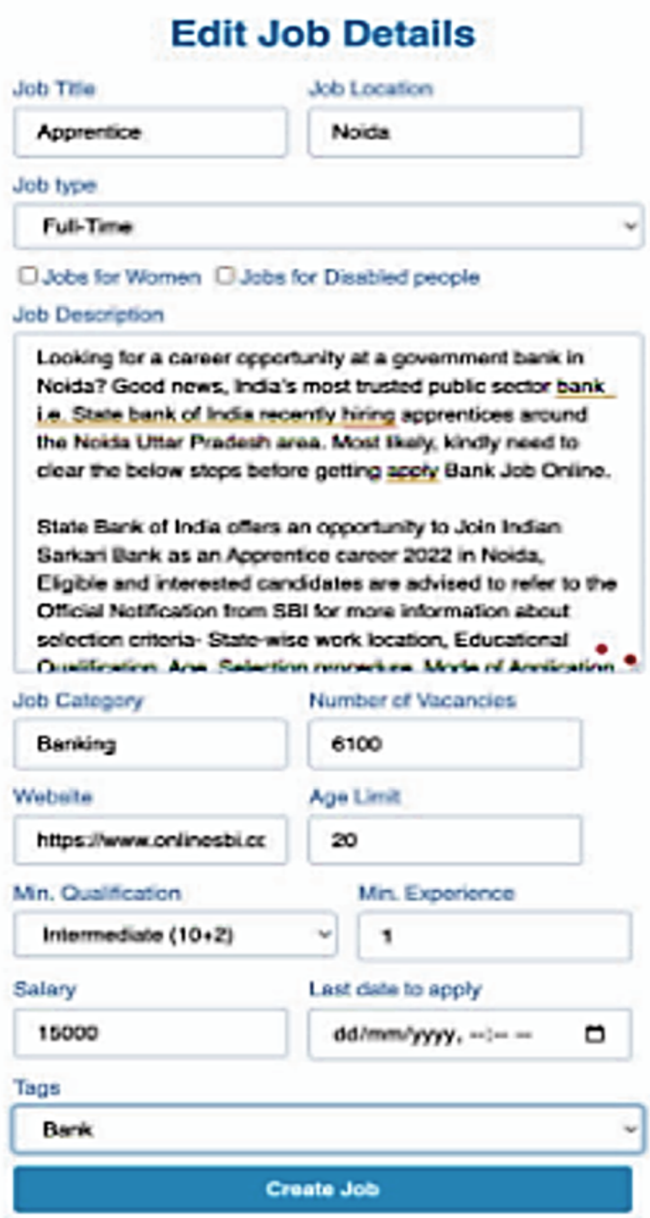

Figure 8: Result obtained for the uploaded PDF

This issue can be improved by feeding the dataset used by the library with more information. Nevertheless, SASHAKT is a potential online employment platform for rural women, linking them with companies searching for intelligent and competent women. The platform promises various features to make the process easier for rural women and employers. Machine learning algorithms, if implemented and integrated with the backend, which can be called through the API endpoints, can provide a smoother and faster-personalized user experience on the platform.

4 Conclusion

Automatic text identification and extraction from images is a crucial study area in content-based information retrieval and text-based picture indexing. Text extraction applications include mobile robot navigation, automobile license detection, recognition, item identification, document retrieval, page segmentation, etc. Based on the data gathered from various methodologies, it has been discovered that morphological and edge-based algorithms may efficiently and effectively locate and extract text from pictures. SASHAKT is an innovative solution that utilizes text extraction summarization and classification techniques of natural language processing techniques to address the need for a more inclusive job search experience for women. It provides an efficient and effective way for women to find job opportunities that align with their skills and qualifications while also addressing the issue of discrimination and bias in the workforce. This study provides valuable insights into the potential of text-based approaches to improve the job search experience for underrepresented groups and paves the way for future research in this area.

Declaration of Competing Interests

he authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding Declaration

This research did not receive any grants from governmental, private, or nonprofit funding bodies.

Author Contribution

Jaspreet Kaur: Supervision, Conceptua;ization and Methodology, Writing- Reviewing; **Pragati Verma**: Conceptualization, Visualization, Investigation, Methodology, Data curation, Writing- Reviewing; **Sanyuktaa Bajoria**: Conceptualization, Visualization, Investigation, Methodology, Data curation, Writing- Original draft preparation, Writing- Reviewing.

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Journal of Computers, Mechanical and Management

Journal homepage: www.jcmm.co.in

JCMM Journal of Computers, Mechanical and Management

Volume 1 Issue 2

Metaheuristics for Multi Criteria Test Case Prioritization for Regression Testing

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Abstract

Banana fiber-reinforced composites are a promising area of research due to their sustainable and renewable nature and physical and mechanical properties. This comprehensive review article analyzed the physical structure, chemical composition, and mechanical properties of banana fibers and the processing methods and challenges associated with their use. The review also covers the different variants of banana fiber-reinforced composites, including their thermal and mechanical properties, current and future applications, and the implications for researchers, engineers, and manufacturers interested in exploring the potential of these materials. The study found that the mechanical properties of banana fiber composites depend on various factors, such as fiber length, diameter, and loading, as well as the type of matrix used. However, more research is needed to understand the full potential of banana fiber-reinforced composites and to address challenges such as the inconsistent quality of fibers and the lack of standardization in processing methods. Despite these challenges, the review highlights the potential for these composites to play an important role in sustainable and eco-friendly construction and manufacturing applications.

Keywords: Banana Fiber-Reinforced Composites; Mechanical Properties; Thermal Properties; Processing Techniques; Sustainable Applications

1 Introduction

The use of composite materials has been increasing in many applications in recent years due to their unique properties and ability to tailor them to specific requirements [1]. Among the various types of composite materials, natural fiber-reinforced composites have been gaining considerable attention due to their environmental and economic benefits over traditional glass fiber composites [2]. These composites combine natural fibers, such as flax, hemp, jute, and kenaf, with polymer matrixes to form a material that combines the properties of both components [3]. Banana fiber, in particular, has emerged as a promising alternative among natural fibers due to its low density, high strength, and biodegradability [4–6]. Banana fibers are obtained from the banana plant's pseudo-stems, a waste product of the banana industry [7]. They can be extracted by simply retting, washing, and drying, making them widely available and cost-effective [8].

*Corresponding author: nithesh.naik@manipal.edu
Received: 13 September 2022; **Accepted:** 02 December 2022; **Published:** 31 December 2022

DOI: 10.57159/gadl.jcmm.1.2.23011.

The mechanical properties of banana fibers are comparable to those of glass fibers, making them suitable for reinforcement in composite materials [9]. The need for sustainable and eco-friendly materials in various industries drives the growing interest in banana fiber-reinforced composites [10]. These composites have been explored for use in applications such as automotive parts, construction materials, packaging, and agriculture [11]. However, there is a lack of comprehensive and up-to-date reviews on the current state-of-the-art in banana fiber-reinforced composites, including their properties, processing techniques, and diverse applications. The properties of banana fiber composites are affected by various factors, including fiber configuration, length, orientation, and surface treatments. The fiber configuration refers to the arrangement of fibers in the composite, which can be in the form of mats, woven fabrics, or randomly oriented fibers. The length of the fibers plays a crucial role in the mechanical properties of the composite, with longer fibers providing higher strength and stiffness. The orientation of the fibers also affects the properties, with fibers oriented in the direction of the applied load providing the highest strength. Surface treatments, such as chemical modification, can also be applied to the fibers to improve their compatibility with the polymer matrix and enhance their properties. The curing process hardens the polymer matrix and creates a stable composite material. [12–17].

The processing techniques for banana fiber composites include extracting and preparing the fibers, fabricating the composites, and curing the polymer matrix. The fibers can be extracted from the pseudo-stems of the banana plant by a simple process of retting, washing, and drying. The fibers are then prepared by cutting them to the desired length and removing any impurities. Various methods can fabricate the composites, including hand layup, compression molding, and injection molding [18–21]. The applications of banana fiber composites are diverse and include automotive parts, construction materials, packaging, and agriculture. Automotive parts made from banana fiber composites have been shown to have high strength and stiffness, making them suitable for use in load-bearing applications. In the construction industry, banana fiber composites have been used as insulation materials and as a substitute for timber in decking, flooring, and roofing applications. Packaging made from banana fiber composites is biodegradable, making it an environmentally friendly alternative to traditional packaging materials. In agriculture, banana fiber composites have been used as plant supports and as a substitute for synthetic materials in irrigation systems [20, 22–27]. This review article aims to provide a comprehensive and up-to-date overview of the current state-of-the-art in banana fiber-reinforced composites, including their properties, processing techniques, and diverse applications. The article will also delve into the various factors that affect the properties of banana fibers, such as fiber configuration, length, orientation, surface treatments, and environmental conditions. A detailed comparison of banana fiber composites with other natural and synthetic fibers will also be provided. Furthermore, the article will highlight the challenges and opportunities for future research in this field. This review aims to provide valuable insights for researchers, engineers, and manufacturers interested in exploring the potential of banana fiber-reinforced composites as a sustainable alternative in various industries.

2 Banana Fibers

2.1 Physical structure and chemical composition

Banana fiber, also known as banana silk, is a type of natural fiber obtained from the stem of the banana plant. The fiber is obtained from the stem's inner layers, known as the pseudo-stem. The pseudo-stem comprises long, tightly packed and woven fibers [8]. These fibers are about 3-5 meters long and have a diameter of about 0.15-0.3mm [5]. The structure of the banana fiber is unique and comprises cellulose, hemicelluloses, and lignin. Cellulose is the main component of the fiber and provides it with strength and durability. Hemicelluloses, on the other hand, contribute to the elasticity and flexibility of the fiber. Lignin, the third component, helps strengthen the fiber's cell walls and provides a rigid structure [28, 29]. The fibers are harvested from the stem of the banana plant when it reaches maturity. The stem is stripped of its outer layers, and the inner fibers are extracted by peeling or cutting. The fibers are then washed, dried, and sometimes treated with chemicals to remove impurities and improve their quality [8, 12, 30]. Banana fiber is characterized by its strength, durability, and versatility. It is known for its ability to resist abrasion and breakage, making it suitable for various applications in the textile industry [31–33]. The fiber is also known for its natural shine and soft texture, making it comfortable to wear and use in various products. In terms of its use, banana fiber is typically used in producing textiles such as clothing, upholstery, and accessories [34–36]. It is also used to manufacture paper products, ropes, and baskets [20, 37–39]. In some countries, it is even used in the construction industry as a substitute for asbestos [40–42]. Table 1 shows the various cells found in fiber of varying diameters [43, 44].

Table 1: The number of various cells and helix angle of banana fibers for various diameters [43, 44].

Diameter of Fiber (μm)	Average Number of Xylem Cells	Average Number of Phloem Cells	Average Number of Sclerenchyma Cells	Total Number of Cells	Helix or Microfibrilar angle (Φ)
100	3	6.25	53	62.25	12
150	3	8.00	70	81.00	11
200	4	7.75	92	103.25	11

The chemical structure of the banana fiber is complex and multi-layered, with three main components that determine its physical and mechanical properties. These components are cellulose, hemicellulose, and lignin [45–47]. Cellulose is a complex carbohydrate that forms the main structural component of banana fiber. It is a linear polymer made up of repeating units of glucose and is responsible for the strength and rigidity of the fiber. Cellulose gives banana fiber high tensile strength and modulus of elasticity, making it ideal for various applications, including textiles, paper, and construction materials [48–50].

Hemicellulose is a complex mixture of polysaccharides that acts as a binding agent between the cellulose fibers [51, 52]. It is responsible for the elasticity and flexibility of the fiber and provides a cushioning effect. Hemicellulose helps to absorb shocks and protect the cellulose fibers from breaking or tearing, making it an important component of banana fiber's overall strength and durability [53–55].

Lignin is a complex organic polymer that acts as a cementing agent, binding the cellulose and hemicellulose fibers together. It provides the fiber with rigidity and toughness, making it resistant to breakage and damage. Lignin also provides banana fiber with its natural brown color, making it suitable for various applications, including textiles and paper products [56–58].

In addition to the three main components, banana fiber contains small amounts of other organic compounds, including waxes, pectins, and tannins [59, 60]. These compounds play a role in the overall chemical composition of the fiber and contribute to its unique properties, including its moisture resistance and durability. Table 2 and Table 3 detail the chemical and physical properties of various cellulosic fibers [**?** 61, 62]. These compounds play a role in the overall chemical composition of the fiber and contribute to its unique properties, including its moisture resistance and durability. Overall, the chemical structure of the banana fiber is highly complex, with a combination of linear polymers, binding agents, and other organic compounds that contribute to its unique physical and mechanical properties. This combination of components makes banana fiber a highly versatile and useful natural resource widely used in various industries, including textiles, paper, and construction.

Table 2: Metal elements present as ions in cellulosic fibers [44].

Fiber	Al^{3+}	Ca^{+}	Mg^{+}	Na^{+}	Si^{4+}
Banana	0.141	5.721	1.771	0.280	1.410
Coconut	0.031	2.440	0.760	2.530	2.561
Bagasse	3.891	3.870	1.320	0.971	27.001

Table 3: Properties of natural cellulosic fibers [61, 62].

Fibers	Composition in percentage weight						
	Lignin	Cellulose	Hemicellulose	Moisture content	Carbon content	Water Absorption	Ash content
Banana	9.00	43.46	38.54	85.60	8.30	50.90	40.10
Coconut	59.40	32.65	7.95	27.10	5.10	51.50	169.10
Bagasse	13.00	30.27	56.73	52.20	4.50	53.10	235.10

2.2 Mechanical properties

The mechanical properties of the banana fiber are an important factor that determines its suitability for various applications, such as textiles, paper, and construction materials. These properties include its tensile strength, modulus of elasticity, elongation at break, and toughness. Tensile strength refers to the maximum stress that a material can withstand before breaking [63]. Banana fiber has high tensile strength, making it suitable for high-strength and durability applications. This strength is due to the presence of cellulose, which acts as the main structural component of the fiber and provides it with resistance to breaking and tearing. The modulus of elasticity measures a material's stiffness and resistance to deformation.

Banana fiber has a high modulus of elasticity, making it ideal for applications where stiffness and stability are important. This property is largely due to cellulose and lignin, which provide the fiber with rigidity and toughness. Elongation at break refers to the amount of extension a material can undergo before breaking. Banana fiber has a low elongation at break, making it suitable for applications where flexibility and stretch are unimportant. This property is largely due to hemicellulose, which provides the fiber with elasticity and flexibility. Toughness refers to the ability of a material to absorb energy without breaking [63]. Banana fiber has a high toughness, which makes it ideal for use in applications where resistance to breakage and damage is important. This property is due to hemicellulose and lignin, which act as binding agents and provide the fiber with cushioning and protection against shocks and stresses. These properties make banana fiber a highly versatile and useful natural resource widely used in various industries, including textiles, paper, and construction. With its unique combination of properties, banana fiber is well-suited for many applications where high strength, durability, and resistance to breakage are important. The mechanical properties vary with the diameter of the fibers, and the same is depicted in Table 4 [64].

Table 4: Mechanical properties of banana fiber of different diameters [64].

Diameter of Fiber (mm)	Initial Young's Modulus (N)	Breaking Strength (N)	% Strain
50.00	32.70	779.07	2.75
100.00	30.46	711.66	2.46
150.00	29.74	773.00	3.58
200.00	27.69	789.29	3.34
250.00	29.90	766.60	3.24

2.3 Factors affecting the properties of banana fibers

The properties of banana fibers, such as their tensile strength, modulus of elasticity, elongation at break, and toughness, are influenced by various factors. These factors can be divided into two main categories: intrinsic and extrinsic. Intrinsic factors refer to those that are inherent to the structure and composition of the fiber itself. These factors include the type and quantity of cellulose, hemicellulose, and lignin in the fiber and other organic compounds such as waxes, pectins, and tannins. These components determine the overall mechanical and chemical properties of the fiber, and variations in their composition can result in differences in the properties of the fiber. Extrinsic factors refer to those external to the fiber and include factors such as the environment in which the fiber is produced, the harvesting and processing methods used, and the end-use application of the fiber. These factors can have a significant impact on the properties of the fiber and can result in differences in the fiber's strength, stiffness, and durability [65, 66].

For example, the environment in which the fiber is produced can affect its properties by changing the moisture content of the fiber, which can impact its strength and rigidity [58, 67]. The harvesting and processing methods used can also influence the properties of the fiber by affecting the fiber's structure, composition, and overall quality [68]. In particular, chemical treatments during processing can change the properties of the fiber and make it more or less suitable for certain applications [69]. The end-use application of the fiber can also significantly impact its properties. For example, fibers used in textiles may need to be soft and flexible, while fibers used in construction materials may need to be strong and stiff. These differing requirements can impact the processing and treatment of the fiber, leading to differences in its properties.

3 Processing Techniques for Banana Fiber Composites

Banana fiber composites have gained significant attention recently due to their excellent mechanical properties and potential applications in various fields. However, the processing of banana fiber composites is a complex process that requires a thorough understanding of the properties and behavior of both the fiber and the matrix. This section will discuss the methods for extracting and preparing banana fibers, the techniques for fabricating banana fiber composites, and the current challenges and opportunities in processing banana fiber composites.

3.1 Methods for extracting and preparing banana fibers

The extraction and preparation of banana fibers are crucial steps in processing banana fiber composites. The fibers are extracted from the banana pseudo-stem, the stem-like structure supporting the banana fruit. The fibers are separated from the rest of the pseudo-stem by a process known as decortication. This can be done manually by peeling the fibers away from the stem or using machine-assisted methods. Once the fibers have been extracted, they are usually washed to remove any impurities, such as dirt, sap, or pith. The fibers are then dried to reduce their moisture content, which is important for preventing mold growth and ensuring the stability of the composites. The dried fibers are cut into small pieces, and their length and diameter are measured [70–72].

3.2 Techniques for fabricating banana fiber composites

Several techniques for fabricating banana fiber composites include hand layup, compression molding, injection molding, and filament winding. The most common technique is hand layup, where the fibers are manually placed into a mold and resin is applied using a brush or roller. The mold is then closed, and the composite is cured under pressure and heat. Compression molding is another popular technique for fabricating banana fiber composites. In this process, the fibers and resin are placed into a preheated mold, and the mold is then compressed to produce the final composite. Injection molding is a more complex process where the fibers and resin are fed into an injection molding machine, and the composite is formed under high pressure. Filament winding is a technique that is often used for producing high-performance composites, such as those used in aerospace and sports equipment. In this process, the fibers are wound around a mandrel, and resin is applied to the fibers as they are being wound. The composite is then cured under heat and pressure.

3.3 Current challenges and opportunities in processing banana fiber composites

Several challenges are associated with processing banana fiber composites, including the fibers' variability, high moisture content, and the need for specialized equipment. The variability of the fibers can result in differences in the composites' mechanical properties, making it difficult to produce composites with consistent properties. The high moisture content of the fibers can also be a challenge, as it can cause the fibers to degrade over time and reduce the strength of the composites. The fibers must be thoroughly dried before they are used in composites. The composites must be stored in a dry environment to prevent moisture from affecting their properties and overcome degradation. Another challenge is the need for specialized equipment to process banana fiber composites. This includes equipment for extracting and preparing the fibers and specialized molding and curing equipment. The cost of this equipment can be a barrier for some companies, especially those in developing countries where banana fiber is abundant. Despite these challenges, there are also many opportunities for processing banana fiber composites. One opportunity is the development of new techniques for extracting and preparing more efficient and cost-effective fibers. This could help reduce the fibers' variability and improve the composites' quality. Another opportunity is the development of new fabrication techniques that can improve the mechanical properties of the composites and make them more suitable for a wider range of applications. This could include the development of advanced composite processing techniques, such as those used in the aerospace and sports equipment industries. In addition, there is a growing interest in using sustainable materials in various industries, and banana fiber composites are a promising alternative to traditional synthetic composites. This has led to increased research and development in banana fiber composites, and there is potential for new applications to be discovered.

4 Variants of Banana Fiber Composites

4.1 Banana fiber-reinforced thermoplastic composites

Banana fiber-reinforced thermoplastics have been extensively studied due to their attractive mechanical and thermal properties. Upon heating above their glass transition temperature (Tg) or melting point, thermoplastic polymeric matrices (TPPMs) soften, allowing for reshaping while retaining high strength and toughness, chemical resistance, good durability, self-lubrication, transparency, and waterproofing [73, 74]. Studies by researchers such as Sapuan, Habibi, Paul, and Zainuddin have investigated using banana fibers as reinforcements in thermoplastics [73–77].

4.2 Banana fiber-reinforced thermoset composites

Thermosetting polymeric matrices (TSPMs) are known for their permanent hardness and rigidity due to cross-linked networks of covalent intermolecular linkages between polymer chains. They have superior electrical and thermal insulation properties, chemical resistance, and high tensile strength [75, 78, 79]. Many researchers have documented the integration of banana fiber with TSPMs, including phenol formaldehyde composites [80–90].

4.3 Banana fiber-reinforced cement composites

Banana fiber-reinforced cement composites have been extensively studied in recent years. According to Zhu et al. [40], using banana fiber in cement reinforcement showed promising results. The researchers studied air-cured banana fiber-reinforced cement composites and found that a fiber loading of 14% by mass resulted in a flexural strength of around 25 MPa and a fracture toughness of 1.74 kJ/m2 [40, 91, 92].

4.4 Banana fiber-reinforced biodegradable composites

Kumar et al. [93] explored using banana fiber and soy protein as a matrix for green composites. They mixed alkali-treated and untreated fiber into soy protein isolate (SPI) with different glycerol concentrations (22-50%) as a plasticizer. The results showed that the tensile strength and modulus of the alkali-treated fiber reinforced with soy protein composites increased to 82% and 96.3%, respectively, at a volume fraction of 0.3. Moreover, the biodegradability test indicated that the composites were 100% biodegradable. Another study used Tamarind Seed Gum as the matrix with banana fiber as reinforcements. The resulting tensile strength was 3.97 MPa. The roasting temperature affected the tamarind seed's tensile strength, with the highest tensile strength obtained at 130 degrees Celsius [94].

5 Mechanical and Thermal Properties of Banana Fiber Composites

5.1 Mechanical properties

The mechanical performance of banana fiber-reinforced polymer matrix composites and their applications have been the subject of numerous investigations [88, 89, 95, 74, 96, 81, 13, 97]. These studies have investigated various aspects of banana fiber-reinforced composites, including the effects of fiber weight and length, hybridization with other materials, and the suitability of banana fiber composites for various industries.

5.2 Thermal properties

The thermal conductivity and diffusivity of banana fiber-reinforced polypropylene (P.P.) composites have been studied with various fiber weight percentages and treatments [76, 98–104]. These studies have shown that the addition of nano clay and other treatments can significantly improve the thermophysical characteristics of these composites. The observations made by various researchers concerning the thermal and mechanical properties of Banana Fiber Reinforced Composites are consolidated in Table 5.

Table 5: Consolidated observations on thermal and mechanical properties of banana fiber reinforced composites.

Author(s)	Composite Specifications	Observations
Pothan et al. [89, 95]	Banana Polyester reinforced composite. Banana Fiber reinforced polyester composites	The combination of 40% wt and 30 mm fiber length significantly increases mechanical strength and moisture absorption. Banana fiber with 40%wt and treated with NaOH reduces stress compared with other cases.
Maleque et al. [74]	Pseudo-stem banana weaved fabric reinforced epoxy composites	Reinforcing with epoxy raised the tensile strength by 90% and impact strength by 40%.
Marriati et al. [96]	Woven banana fiber and pandanus fiber reinforced polyester composites produced by vacuum bagging technique	Woven banana fiber has better impact and flexural properties than pandanus fiber.
Haneefa et al. [81]	Glass fiber hybridized with banana fiber	Raising the fiber weight percentage increased tensile and flexural strength.
Biswal et al. [98]	Banana Fiber with Polypropylene matrix and added nano clay	Thermal Stability and Tc value increase significantly.
Kulkarni et al. [102]	Banana Fiber hybrid composites with fly-ash and polypropylene fillers	Improved mechanical and thermal properties.
Mohan et al. [103]	Banana Fiber reinforced with nano clay and treated with NaOH	18% increase in high-temperature deterioration.
Taj et al. [105]	Banana Fiber with Polylactic acids prepared by melt bending technique.	Better thermal stability and higher storage modulus.

6 Applications of Banana Fiber Composites

Banana fiber composites are increasingly being used in diverse applications due to their exceptional mechanical properties and potential for sustainability. Their applications can be seen in the building and construction, automotive, sports equipment, and packaging industries. This section will discuss the current and potential applications of banana fiber composites, the advantages and limitations of using banana fiber composites in different applications, and case studies of successful applications of banana fiber composites. Banana fiber composites are increasingly used in the building and construction industry as a sustainable alternative to traditional synthetic composites. Using these composites in roofing materials, flooring materials, and wall panels has proven to be a game-changer, offering several benefits over synthetic composites. Firstly, banana fiber composites are eco-friendly and biodegradable, making them an attractive option for green construction projects. This is important, especially as the world is becoming more conscious of the impact of construction on the environment. Secondly, they have a high strength-to-weight ratio, making them ideal for roofing, flooring, and wall panel applications. This is because the composites offer a good balance of strength and durability, making them suitable for building and construction applications. However, one limitation of banana fiber composites in the building and construction industry is their limited availability, which could increase their cost. Nevertheless, despite this limitation, banana fiber composites in the building and construction industry are expected to grow as people become more environmentally conscious and demand eco-friendly building materials.

The automotive industry has embraced banana fiber composites as a key material in producing composite parts such as bumpers and body panels. These composites have a remarkable strength-to-weight ratio, making them a superior choice for automotive applications that require weight reduction. Additionally, their impact resistance and ability to withstand harsh weather conditions make them well-suited for the demands of the automotive industry. Despite the benefits, one potential drawback of using banana fiber composites in the automotive sector is their limited availability compared to traditional synthetic composites, which may drive up costs. The sports equipment industry has embraced banana fiber composites in producing sports equipment, such as golf clubs and tennis rackets. These composites offer several advantages over traditional materials, including a high strength-to-weight ratio and durability, making them ideal for applications in the sports industry where a balance of strength and weight is crucial. Additionally, using eco-friendly and sustainable materials aligns with the values of many sports enthusiasts and consumers. However, like other industries, one limitation of using banana fiber composites in sports is their limited availability, which could result in a higher cost than traditional synthetic composites. Despite this, the increasing demand for sustainable and high-performing materials may drive the development and production of banana fiber composites, making them more accessible and cost-effective.

In the packaging industry, banana fiber composites are a sustainable alternative to synthetic composites. The use of banana fiber in packaging provides several advantages, such as being eco-friendly, biodegradable, and having a high strength-to-weight ratio. These properties make it ideal for packaging products that need to be lightweight and durable. However, one of the limitations of using banana fiber composites in the packaging industry is their limited availability, which can lead to an increase in cost compared to traditional synthetic composites. Despite this, the use of banana fiber composites in the packaging industry is growing as consumers become more conscious of the impact that packaging has on the environment and demand more sustainable packaging solutions. Other industries, such as aerospace and medicine, also have the potential for using banana fiber composites due to their exceptional mechanical properties. However, limited availability may still be a hindrance in these industries. In addition to these applications, there is also potential for using banana fiber composites in the aerospace and medical industries, where high-performance composites are required. However, the limited availability and higher cost of these composites may pose a challenge in these industries.

7 Conclusion

In conclusion, this comprehensive review has highlighted banana fiber-reinforced composites' physical structure, chemical composition, and mechanical properties. The use of banana fibers as reinforcements in various matrices has shown promising results, particularly regarding the composite's mechanical and thermal properties. Banana fiber composites' current and future applications range from construction and packaging materials to biodegradable composites. However, despite the potential of banana fiber-reinforced composites as a sustainable alternative, several challenges still need to be addressed to realize their potential fully. Some of the key research gaps in this field include the following:

- Improved fiber extraction and preparation techniques to increase the fibers' yield and reduce production costs.
- Development of more efficient and cost-effective methods for processing banana fiber composites, including formulating new composite systems and optimizing the processing parameters.
- Further investigation into the compatibility of banana fibers with different types of matrices and the influence of the matrix type on the properties of the composites.
- Study banana fiber-reinforced composites' long-term durability and stability, including their resistance to environmental factors such as moisture and U.V. radiation.
- Exploration of new applications and markets for banana fiber composites, particularly in biomedical engineering and energy storage systems.

These research gaps provide ample opportunities for researchers, engineers, and manufacturers to explore the potential of banana fiber-reinforced composites as a sustainable alternative. By addressing these challenges, the future of banana fiber composites can be realized as a versatile and sustainable material.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding Declaration

This research did not receive any grants from governmental, private, or nonprofit funding bodies.

Author Contribution

Nithesh Naik: Conceptualization, Writing-Reviewing **Nilakshman Sooriyaperakasam**: Conceptualization, Writing-Reviewing **Mahmood Al Abdali**: Conceptualization, Writing-Reviewing **Yash Parmar**: Conceptualization, Writing-Reviewing **Shresht Singh**: Investigation, Methodology, Data curation, Writing-Original draft preparation **Tejas Iyer**: Investigation, Methodology, Data curation, Writing-Original draft preparation **Chirag Agarwal**: Investigation, Methodology, Data curation, Writing-Original draft preparation **Jeswanthi Tirupathi**: Investigation, Methodology, Data curation, Writing-Original draft preparation

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