Chapter

Experimental Investigation of the Mechanical and Thermal Properties of Natural Green Fibres

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Abstract

Biomaterials and green products rely heavily on natural lignocellulosic fibres. They have a wide variety of potential capabilities and characteristics, making them suitable for many applications. These fibres offer all the components required for renewable energy deployment. Fibre polymers from Jharkhand such as palm, datura, lemon, and mustard were studied for their thermal, mechanical, and interfacial adhesion properties. There were also tests on tensile strength, elongation to break, and thermogravimetric analyses (TGA). The effects of heating on weight loss, water loss, and disintegration have also been studied. A comparison was made between frequently used global fibres and the fibres analysed in this research article. Jharkhand's fibres are shown to be more compromising than worldwide fibres. Palm fibres have excellent tensile strength (160 MPa) and modulus of elasticity (5 GPa). The thermal behaviour of lemon and datura fibres is the most similar. Palm and mustard fibres respond similarly in warm temperatures. At 140°C and 240°C, mass loss was 18.8 and 24.3%, respectively. TGA shows that the studied fibres are more suited for industrial applications owing to their stable thermal behaviour. Plastics, textiles, packaging, and papers may all use palm fibres in insulators, circuit boards, switches, and terminals, as well as in furniture and window frames.

Keywords: green materials, lignocellulosic fibres, mustard, eco-friendly, datura, palm, lemon

1. Introduction

New bio-product materials have been created to reduce dependency on petroleum commodities, potentially leading to sustainable green products and cleaner manufacturing [1]. Many countries have emphasised the use of bio-based renewable resources because of the rising cost of petroleum commodities, climate change, and the world's drive toward global sustainability [2]. Furthermore, in order to ensure long-term sustainability, the government has recognised the importance of available natural resources, their proper utilisation, and waste management, which has resulted in the development of better schemes, regulations, and promotions for natural bio-based materials, such as natural fibre composites (NFCs). Furniture, automotive, agriculture, construction, packaging, aerospace, and other industries have recently embraced natural fibre composites to replace conventional materials [3]. NFCs provide a number of advantages over traditional synthetic materials, including being recyclable, abundant, lighter in weight, degradable, and less expensive. NFCs also benefit from being a green product since they are recyclable and degradable in nature, contributing to the goal of environmental sustainability. Green commodities generated from agricultural waste would open the way for new renewable resources while also providing a source of revenue for many developing nations [4]. Plants (lignocellulosic) are natural fibres that may be used as polymer reinforcement, making them an excellent renewable resource. To develop new types of biomaterials that are ecologically friendly [5–7]. They might also be regarded a wonderful solution for reinforcement from an environmental and economic standpoint. They are more ecologically friendly, lighter, and require less energy, making them more sustainable from a sustainability aspect. Natural fibres are classified according to where they come from in the plant: leaf, fruit, seed fibres, stem fibres, bast fibres, and skin. Natural fibres are in great demand in a variety of sectors, including furniture, automotive, agricultural, construction, packaging, and aerospace, due to their high specific characteristics and cheap cost. Constituent qualities, maximum manufacturing temperature, degradability, orientation, volume fraction, fibre length, and geometry all have a role in the overall features and attributes of a bio-composites product. However, while designing green goods, mechanical and chemical qualities are the only two factors that are taken into account to a higher degree, since there is a correlation between natural fibre’s chemical properties and their equal mechanical performance [8, 9].

Nowadays, lignocellulosic fibres are employed as a stand-alone and primary component of bio-composites. They are utilised separately because their inherent qualities are difficult to alter or modify in comparison to their equivalents, such as polymers, whose properties are readily manipulated. This might explain why natural fibres have less applicability in numerous industries than polymers, which have been widely employed in recent years. Natural fibres in bio-composites, on the other hand, might be useful in supplying alternative materials for green solutions [10].

This study presents a fresh approach to researching natural fibres accessible in India’s Jharkhand area, particularly lignocellulosic fibres, and testing their mechanical and environmental behaviour from a variety of technical perspectives. This would ensure the creation of an ideal database of materials that could be crucial in developing green materials that are both eco-friendly and cost-effective, as well as developing future sustainable materials with broad industrial applications and opening doors for further bio-materials research.

2. Materials and methods

Diverse lignocellulosic wastes have been collected in abundance from several areas in Jharkhand (the north-eastern portion of India). In this work, we measured the physical properties of polymers.

Lignocellulosic fibre interface characteristics and thermogravimetric analyses were explored with the purpose of selecting lignocellulosic fibre.

2.1 Selection of fibres

The preliminary inquiry was carried out in a specified manner in accordance with assessment criteria in order to identify the best suited fibres. The basic selection for the compatibility of the different agricultural waste fibres was made. The availability of resources (fibres), cost estimate, dependable qualities necessary to complete the job (mechanical property), renewal duration, and material density are all included in this assessment criteria [11, 12]. A few species were omitted from further examination because they did not meet the original criterion. Lemons, palms, *Datura stramonium* (hence referred to as datura) and mustard residue fibres were used to determine the results. As previously stated, all of the fibres were readily accessible in large amounts in Jharkhand. As a result, they met the physical and mechanical requirements for the presentation while also being less expensive.

Following that, suitable fibre samples were investigated for mechanical and thermal examinations to determine their prospective capabilities. Samples were processed and adaptable in accordance with the test's requirements. The specimen to be tested for the tensile test, for example, was held at 120 mm in length with a gage length of 50 mm. Their diameter, on the other hand, has fluctuated based on the fibre variations and plant type. As a result, the averaged cross-sectional area estimates are based on the measurements recorded for each of the 10 possible gage length interpretations (for every 5 mm). Tensile strength, Young's modulus, and elongation obtained before the fracture point were all tested on all of the manufactured samples. Five testing trials were conducted for each fibre material, according to ASTM D 3822/01, and the average value was picked for future analysis. The 3365 Instron (**Figure 1**) is utilised for the tensile test, with a crosshead speed of 2.0 mm/min.

Furthermore, all of the fibres used in the study were from agricultural waste and were tested for thermal properties (**Table 1**). It was examined to determine the percentage loss of weight characteristics in touch with the combustion and the heating impact of the combustion. The conclusion is that they are environmentally beneficial materials for the manufacturing process.

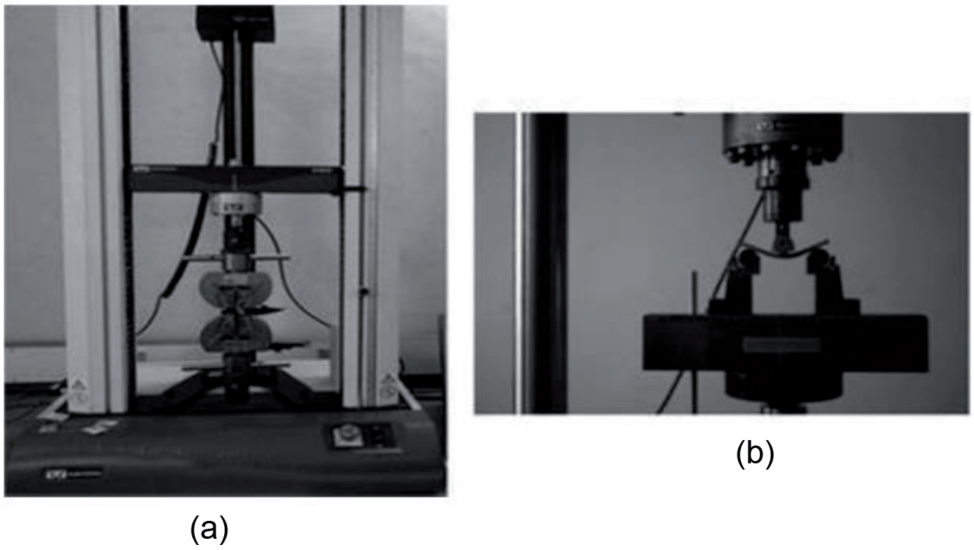

Figure 1.
UTM Instron 3365. (a) Tensile, (b) flexural.

Polymers	Melt flow rate at 230°C and 2.2 kg load	Yield tensile strength (MPa)	Density (kg/m^3)
Polypropylene (PP)	12.5 g/10 min	34	906
Low-density polyethylene (LDPE)	0.85 dg/min	11	921
High-density polyethylene (HDPE)	0.7 g/10 min	30	960
Polyvinyl chloride (PVC)	—	K value 68	569

Table 1.
Physical properties of the selected polymers.

2.2 Thermogravimetric analysis (TGA)

Thermogravimetric analysis (TGA) is used to identify changes in physical characteristics and biochemical processes that occur to fibres when the temperature is allowed to rise at the same rate as the temperature, since it is critical to retain information on fibres from agricultural wastes in terms of water loss and decomposition. TGA experiments are carried out with the aid of a NETZSCH TG 209/F1 apparatus (**Figure 2**). Thermal Stability was measured with several specimens at a heating rate of 10°C/min across the whole temperature range of 31–300°C and 500°C.

2.3 Characteristics of the interfacial zone

The pull-out technique is a useful tool for examining the interfacial characteristics of different polymer fibres. Because the properties of the fibre-matrix interface have a substantial influence on composite materials' mechanical performance. The interfacial effects of the debonding and pull-out processes may be determined using this approach. The fibre was put into the polymer and a tensile test was conducted in the pull-out inquiry. In this testing method, the polymer and the free tip of the fibre are

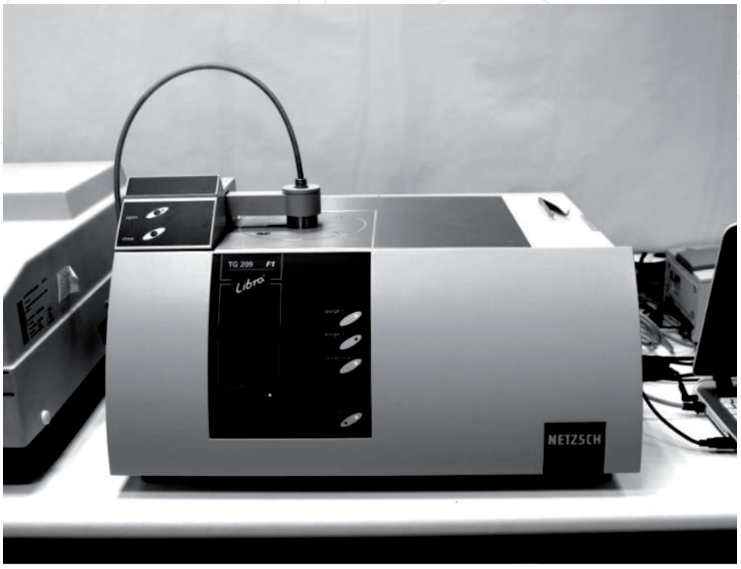

Figure 2.
NETZSCH TG 209/F1.

both gripped and pulled apart. The fibre was removed without causing the polymer to split. This data suggests that the fibre/polymer interface was a failure of adhesive rather than polymer or fibre cohesiveness. The durability and capacity of polymers or fibres were explored in order to build environmentally acceptable materials. For this aim, a pull-out technique is employed to determine the maximum load capacity that can sustain the fibre/polymer [13].

The extrusion procedure was chosen for the preparation of the pull-out sample's method of hot mixing. For each specimen, 31 cm of rectangles were cut. The sample is constructed such that each fibre is implanted along the rectangle's centre axis. An optical microscope is used to measure the specimen's length and diameter. With the aid of a universal testing equipment, the specimen is permitted to act a tensile load (Instron 3365). The load-displacement graph is being recorded, and the crosshead speed is being held at 2.0 mm/min.

3. Result and discussion

Various lignocellulosic fibres have been discovered in the Jharkhand region in this investigation. Environmental waste is a consequence of using green bio-based goods instead of conventional resources. Unfortunately, Jharkhand is not doing enough to make use of its agricultural lignocellulosic waste. The qualities of this fibre and the potential alternative uses of global fibres remain unknown to industrialists. In the creation of biomaterials for green goods, as well as the search for materials that will help in the finding of renewable sources of materials for green products, these fibres will be of use. As a result, developing countries and industrial markets like India and its neighbours will see an increase in their gross domestic product.

3.1 Mechanical investigation

A mechanical experiment was conducted to determine the mechanical characteristics of Jharkhand's agriculture waste fibres. The tensile testing procedure is used to determine Young's modulus, length elongation before fracture, and maximum tensile strength. To determine the tensile strength, all of the samples provided for the research have been finished. The potential possibilities of biomaterials have been discovered as a result of this research [14]. It is comparable to traditional fibres such as coir, sisal, flax, hemp, jute, and others that are often used in literature. **Figure 3** depicts the mechanical behaviour (stress-strain) of lignocellulosic fibres. The tensile strength of natural fibres is seen in **Figure 4**. Because of the larger cellulose concentration in its constituents, palm fibre has the most substantial tensile strength of 160 MPa, whereas mustard fibre has 60 MPa. Datura has the lowest value, which is less than 8 MPa. As a result, the tensile strength of fibres is arranged in the following order: palm, mustard, and lemon fibres.

Figure 5 also depicts the elongation variation required to break the property of Jharkhand agro-based fibres. It demonstrates that palm fibres have the highest elongation value to break the percentage. Palm fibre, mustard, and datura, respectively, have 0.078%, 0.06%, and 0.026%. The lemon type fibre, on the other hand, has the lowest percentage value, at 0.025%. Except for the palm fibres, the previous observations of elongation to break the % value of mechanical qualities are extremely similar. If just a single criterion is used for the selection process, it may result in paying little attention to the other fibre materials if one characteristic is overlooked. As a result, it is

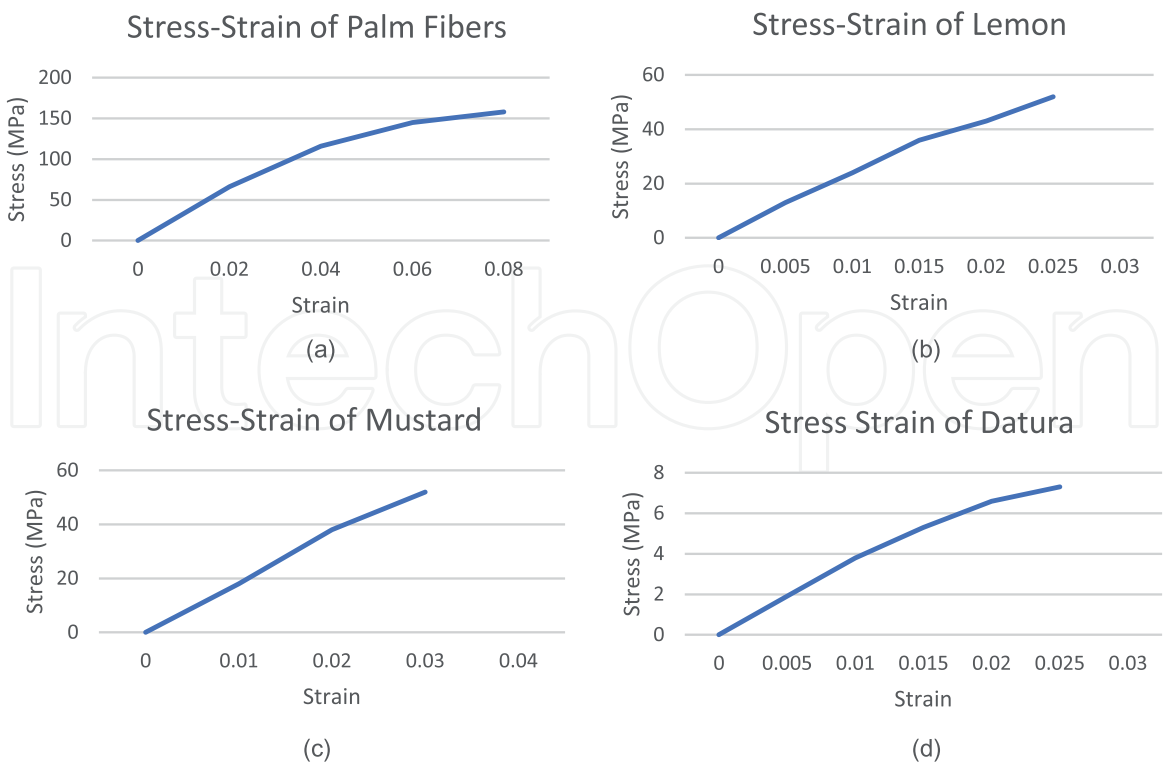

Figure 3.
Stress-strain diagram of (a) palm fibres, (b) lemon, (c) mustard and (d) datura.

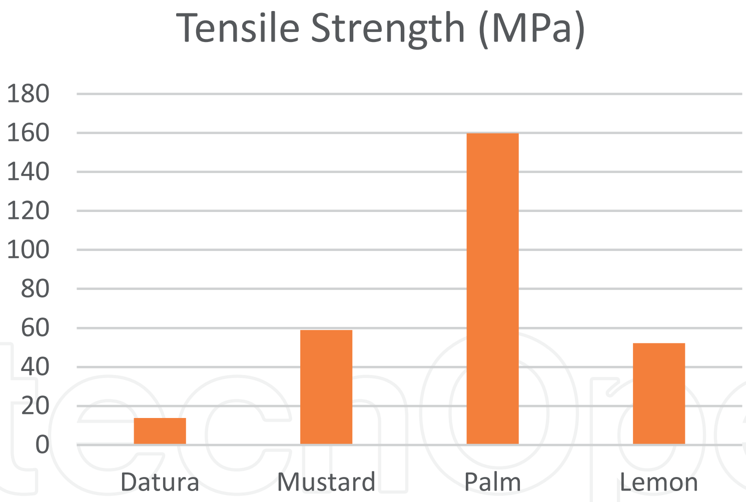

Figure 4.
Tensile strength of fibres compared.

concluded that more than one criterion should be used in the selection of natural fibre constituents for biomaterial evaluation.

Young's modulus criteria with mechanical parameters for Jharkhand agricultural waste fibres is shown in **Figure 6**. Palm fibres have a Young's modulus value of 5.02 GPa, whereas lemon fibres have a value of 2.71 GPa. Similarly, mustard-type fibres have a modulus of elasticity closer to 2.35 GPa, but datura only possesses 0.34 GPa. It was discovered that fibres from Jharkhand had a higher Young's modulus, indicating that they would make superior natural reinforced polymer composites.

The intrinsic capabilities of regularly used fibre materials and Jharkhand lignocellulosic fibres have been found. Young's modulus and tensile strength of Jharkhand

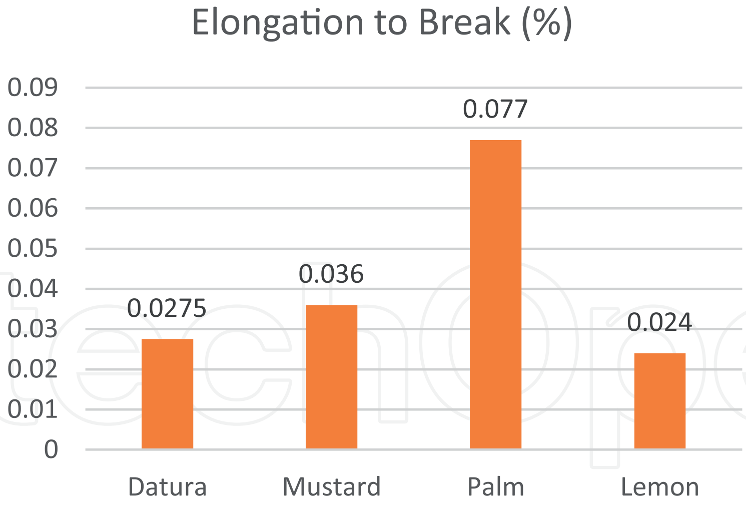

Figure 5.
Elongation to break % of fibres compared.

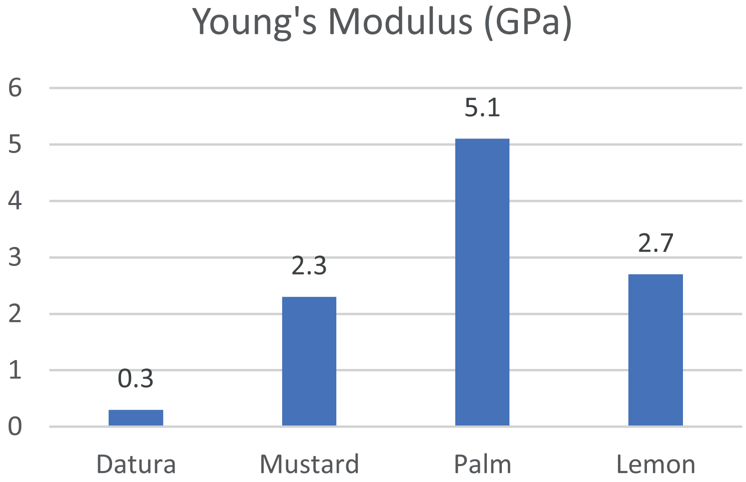

Figure 6.
Young's modulus % of fibres compared.

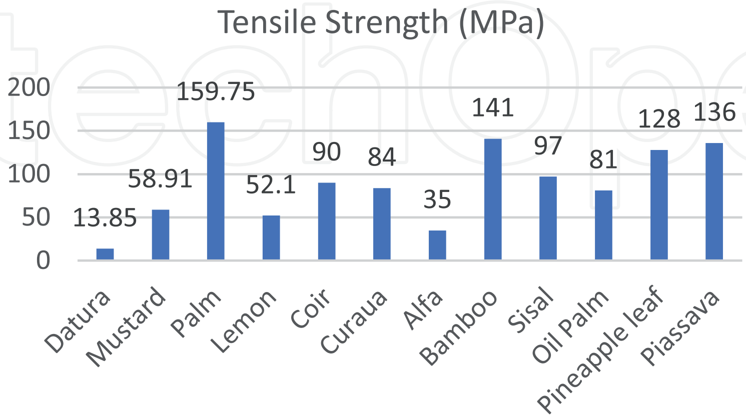

Figure 7.
Tensile strength of fibres compared with other commonly used natural fibres.

fibres and fibres from across the globe have been compared. **Figures 7** and **8** show how this is done. The table lists all of the governing mechanical characteristics of the most regularly used fibres. **Figure 7** shows that palm fibres have the greatest tensile strength value when compared to lemon and mustard fibres.

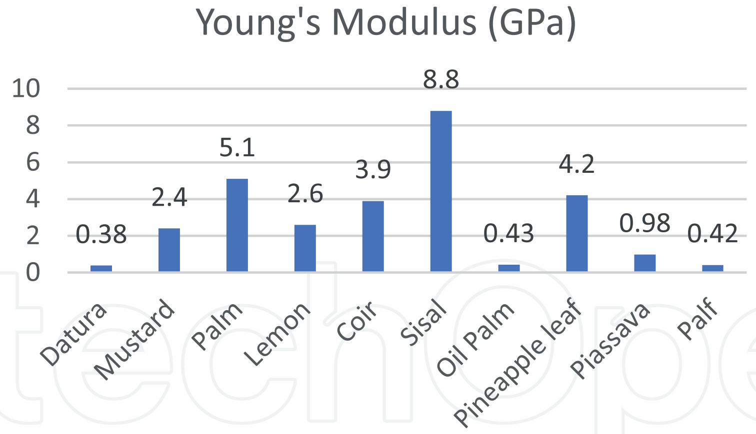

Figure 8.
Young's modulus of fibres compared with other commonly used natural fibres.

Figure 8 shows a comparison of the tensile modulus of the most regularly used fibres. Except for sisal, it is obvious that Jharkhand fibres have a higher modulus value than the other fibres. The Young's modulus of mustard and lemon fibres, for example, is higher than that of palf, oil palm, and piassava fibres. As a consequence, Jharkhand's agro-based waste fibres have a better chance of becoming biomaterials for industrial use.

3.2 Thermographic analysis (TGA)

Agricultural waste produced all sorts of fibres studied in the literature. Thermal procedures have looked at the influence of heat on their characteristic of weight loss before combustion to see whether this material is acceptable for future manufacturing processes of environmentally friendly products. TGA testing was also used to track the physical vagaries of raising the temperature rate at a regular pace. This approach was also used to regulate the chemical characteristics of the fibres. Water losses must be determined throughout the breakdown process particularly for agricultural waste fibres [15]. The TGA research revealed that palm, datura, lemon, and mustard are all thermally stable, with minor/negligible behaviour when it comes to mass losses.

Thermal stability was measured with many specimens in the temperature range of 31–300°C and 500°C at intervals of 10°C/min heating rate and found to be stable. As the temperature rose, people began to lose weight as a result of the heat. It was discovered that the first percentage loss in mass is 7.2% up to 140°C. The cause for this is the evaporation of water, as well as the presence of lignin. Depending on the fibre type, the moisture content varies. By raising the temperature over this point, the other elements of fibres, such as hemicellulose and lignin type cellulose, were harmed. In this study, the degradation degree of lemon fibres was shown to be divided into three phases. The second and third levels begin from 190–240°C and 240–300°C, respectively. At these two levels, the percentage of deterioration was 5.17% of mass and 14.82% of weight, respectively.

The entire analysis of the fibres addressed in this paper is shown in **Figure 9**. This diagram depicts the thermal behaviour of fibres in terms of stability and degradation. In the experiments, lemon and datura fibres were shown to be more stable for the initial temperature range of 140–240°C. At a temperature of 240°C, datura and lemon fibres are steadier in percentage weight loss than palm and mustard fibres at 140°C. Except for lemon fibres, all other fibre materials studied had a weight decrease of greater

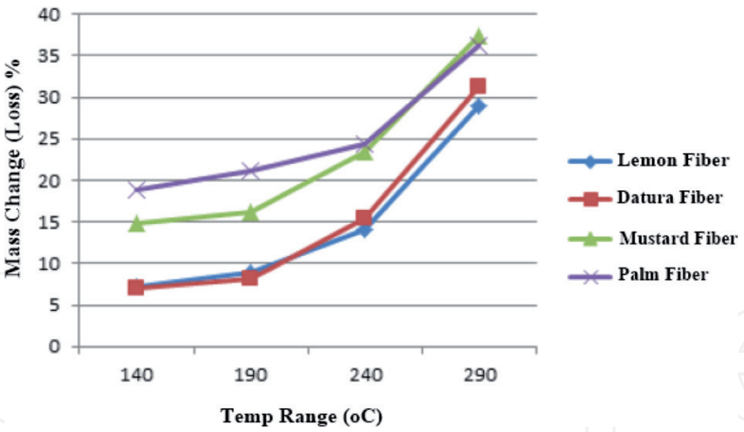

Figure 9.
Thermal stability of fibres compared.

than 30%. This fibre material's stable feature is better suited for biomaterials based on polymers for industrial applications requiring a greater thermal stability value.

As a result of the experiments, it has been theoretically shown that fibres from Jharkhand agricultural wastes are more appropriate for industrial applications owing to their better mechanical and electrical characteristics. Insulation in door panels, covering door racks, window frames, home railings, furniture industries, paper, textiles, insulated electronics, circuit boards, terminals, switches, and dielectrics are just a few examples.

Figure 10 shows that, when it comes to divergence to percentage mass loss, Jharkhand fibres outperform other fibre types. Datura and lemon have been demonstrated to have a lower weight reduction percentage than bagasse, banana, bamboo, pineapple leaf, and phoenix SP. It demonstrates Jharkhand's increased stability and enhanced opportunities for green product manufacturing.

3.3 The pullout test

The pull-out technique is one of the most important ways to confirm that lignocellulosic fibres and the different polymers investigated in this study are compatible. By assuring the interfacial bonding capacity, this approach determines the maximum load applied to the fibre up to which it can withstand the load limit. This approach may be used to determine if agricultural waste fibres and polymer components are

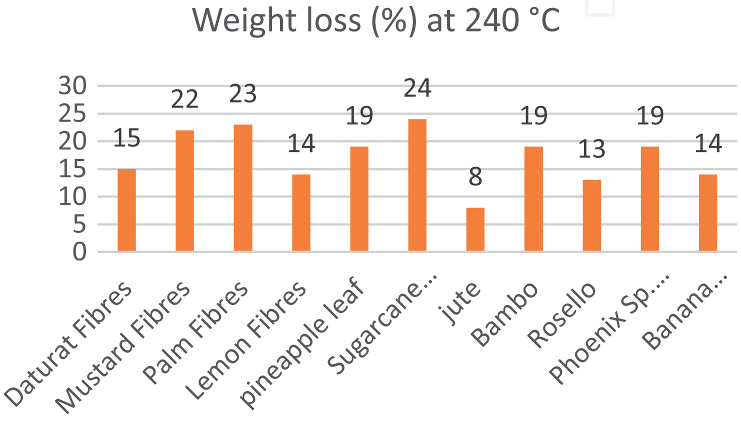

Figure 10.
Weight loss (%) of fibres compared with other commonly used natural fibres.

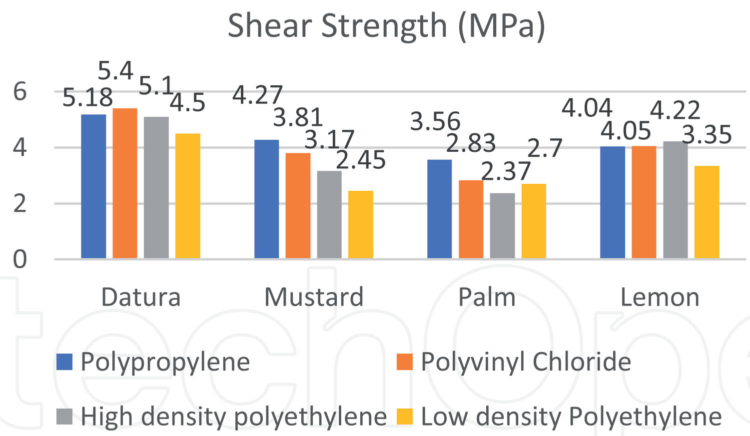

Figure 11.
Shear strength of fibres compared through use as polymers.

compatible. It was decided to prepare samples for the test hot mixing extruding technique. Polypropylene, polyethylene of high density, polyethylene of low density, and epoxy were among the samples bought and prepared for the pull-out test [9, 16, 17].

Figure 11 depicts the shear strength of the different polymer interfaces. The graph shows that datura fibre has the best interfacial bonding, and that PVC polymer has a shear strength of 5.3 MPa. Datura's most important attribute is its coarser surface compared to other polymers, which allows for sticky properties. Because of their flat surfaces, mustard and palms have reduced interfacial bonding.

4. Conclusion

This research successfully achieves the interfacial properties of Jharkhand lignocellulosic fibres. Jharkhand fibres' thermal and mechanical properties were also examined in laboratory tests. A side-by-by-side comparison of foreign and Jharkhand fibres was carried out in order to assess their inherent capabilities and usefulness. Because of its increased mechanical strength, thermal stability, and strong adhesive forces at surfaces, the Jharkhand lignocellulosic was determined to be more suited. For biomaterials applications, Jharkhand's fibres have also been shown to be better compatible with a variety of polymers. Palm-type fibre materials have higher mechanical strength, elongation to break, and tensile strength than mustard fibres. The thermal stability of the abovementioned fibres is determined to be better in the case of lemon fibres, while datura fibres are best at 240°C and 290°C owing to their mass to loss percentage.

Lemon and datura fibres are the most ideal for thermal properties when compared to pineapple leaf, bamboo, roselle, bagasse, and phoenix SP, since they have a lower weight ratio at 240°C. Furthermore, after a thorough examination of fibre materials, it is possible to conclude that, due to their cheap cost and environmental friendliness, widespread manufacturing of these green goods might be boosted for developing nations. With the Jharkhand fibre's better interfacial bonding, sustainable businesses may now produce green products. PVC and datura fibres were found to be the best fibres for shear loads with all types of polymers in this paper. Doors, textiles, packaging and papers, furniture, window frames and electrical applications such as insulators, circuit boards and dielectrics are just a few of the many uses for Jharkhand waste agro fibres.

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Data availability statement

All data, models, and code generated or used during the study appear in the submitted article.

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