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Research Article

Mechanical Properties of Polymer Composites Reinforced with Alkaline-Treated Natural Fibre

I. Paul Theophilus Rajakumar,[1] D. Raguraman,[2] J. Samson Isaac,[3] R. Suthan,[4] Sumanta Bhattacharya,[5] Asiful H. Seikh,[6] S. M. A. Khan,[7] and Ishwarya Komalnu Raghavan[8]

[1]*Department of Mechanical Engineering, Panimalar Institute of Technology, Poonamallee, Varadarajapuram, Tamil Nadu 600123, India*
[2]*Department of Automobile Engineering, Bharath Institute of Higher Education and Research, Chennai 600073, India*
[3]*Department of Biomedical Engineering, Karunya Institute of Technology and Sciences, Karunya Nagar, Coimbatore, Tamil Nadu 641114, India*
[4]*Department of Mechanical Engineering, Panimalar Engineering College, Poonamallee, Varadarajapuram, Tamil Nadu 600123, India*
[5]*Department of Textile Technology and Biotechnology, Maulana Abul Kalam Azad University of Technology, Kolkata, West Bengal 700064, India*
[6]*Mechanical Engineering Department, College of Engineering, King Saud University, P.O.Box 800, Al-Riyadh 11421, Saudi Arabia*
[7]*Department of Mechanical and Industrial Engineering, Ryerson University, Canada*
[8]*Department of Electromechanical Engineering, Faculty of Manufacturing, Institute of Technology, Hawassa University, Ethiopia*

Correspondence should be addressed to Ishwarya Komalnu Raghavan; ishwarya138@hu.edu.et

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The mechanical characteristics of a high impact polyethylene composite (HIPC) reinforced with abaca fibre (AF) are investigated in relation to fibre loading. An alkaline behaviour was used to improve the characteristics of the abaca fibre. With a fibre length of 100 mm, five different fibre loadings of the abaca fibre were used to create the samples of the composite (25, 35, 45, 55, and 65 wt percent). The object was made using compression moulding with unidirectional fibre orientation. The influence of fibre loading was investigated using tensile, hardness, and density tests. In an experiment, it was shown that with 55 percent fibre loading, tensile strength was 312 percent higher than without, and Young's modulus was 545 percent higher than without. While this was happening, the hardness and density of the AF/PE composites were found to be quite similar, with minor increases from 25 wt percent to 65 wt percent AF loading in comparison to the control sample's zero wt percent AF loading. 67.42 Shore-D and 1.014 g/cm^3 are the highest values. The alkaline treatment of the AF/PE composite had a substantial influence on mechanical characteristics, according to the findings.

1. Introduction

Researchers, particularly in the automation, shipping, packing, woodworking, and constructions, have recently shown substantial attention in growth of biodegradable fibre reinforced polymer (BFRP) compound by means of an alternative to traditional materials. Plant fibres' plentiful availability and accessibility are the primary drivers of a growing interest in sustainable technologies [1, 2]. Global warming and the exhaustion of fossil fuels have prompted an increase in interest in organic fibre mixtures as a substitute [3]. Biodegradable composites can be made better by using natural fibres like those found in plants. Aside from its good mechanical and dielectric qualities, natural fibre composites have other environmental advantages, such as being biodegradable and renewable. The goal of this work is to evaluate a techno-economic feasibility based on environmental effect [4, 5]. They are also lightweight and inexpensive and have a decent specific strength. Nowadays, a wide variety of natural fibres are in wide usage. Rice husk, abaca, bamboo, coir, jute, sisal, kapok, coconut, and oil palm fibres are just a few of the natural composite fibres that have been studied by researchers for their potential application in the industry [6]. Abaca fibre was used as a reinforcing material in this investigation, and polyethylene was used as the matrix.

Lightweight, low-cost, nontoxic, biodegradable, and high specific stiffness are some of the compensations of utilizing organic fibres in trading [7, 8]. In the automobile and aircraft industries, these properties make natural fibre–reinforced composites ideal. Automobiles must be designed in a way so that at least 85% of the vehicles weight age can be reused or reprocessed [9]. Fibre strength is a key consideration for prospective industrial use. Fibre-reinforced composites can be made from natural fibres including sisal, flax, ramie, bamboo, and abaca, which have high tensile strengths [10].

Abaca is valued for its high mechanical strength, salinity resistance, and long fibre length. The use of abaca fibre as a reinforcing ingredient including both thermosetting and thermoplastic polymers has indeed been demonstrated. Bananas of the abaca family are cultivated commercially in the Philippines as a source of income. Tensile strength (500–800 MPa) and modulus (40–60GPa) of Abaca fibre are high. The tensile strength (511–635 MPa) and Young's modulus (9.4–22.0GPa) of sisal fibre. Daimler AG vehicles have been protected using abaca fibre-reinforced composites. To meet the demanding criteria of road transportation, abaca fibres must be resistant to moisture and other environmental factors such as the weather and stone impact [11, 12]. Accurate and efficient commercial use of abaca fibres necessitates knowledge of the fibres' specific physical and chemical characteristics and assembly–function connection. Because of their moisture content and weak interfacial interaction with the matrix material, natural fibres are not ideal for composites [13]. In high-load applications, natural fibres still have not totally replaced conventional fibres. Only sections like as door panels, seats, and other interior panels are commonly made with natural fibre-reinforced composites. Surface modification of natural fibres is becoming increasingly relevant as a result of their enormous industrial potential [14, 15]. More and more studies are being done to progress fibre bond and lessen moisture content, which are two key areas of research in the field of fibre improvement.

For textile and natural composite goods, the use of abaca fibre (AF) as a reinforcing material is highly desirable [16]. As a result, the natural complex specimens manufacturing may diminish contamination, waste management issues, and other environmental difficulties by utilizing AF. Because of its high moisture absorption and low compatibility with various polymer matrixes, the usage of natural fibres has considerable drawbacks [17–19]. The natural fibres' surface can be altered to promote adhesion among the hydrophilic natural fibre and the hydrophobic polymer matrix using an appropriate treatment, such as alkaline treatment or heating. According to [20] findings, alkaline behavior better the composites' ductile toughness and modulus. Abaca fibre from Josapine cultivar through alkaline treatment will be used as reinforcement by researchers in this project in an effort to learn more about the mechanical characteristics of polyethylene composites [21]. Alkaline treatment of AF's surface and fibre extraction was the primary focuses of this study. Tensile stress, hardness, and bulk density of the AF/PE composite have been measured.

Lignocellulosic fibres are those that come from plants. To put it another way, lignocellulose materials include wood, agricultural waste, aquatic plants, and grasses. The composition, characteristics, and structure of plant waste fibres make them appropriate for a variety of applications, including composites, textiles, and paper pulp [22]. Aside from that, plant fibres can be utilized to make everything from fuel to chemicals to enzymes to food. A wide range of fibres from flax to pineapple leaf fibre are utilized in textile and packaging industries as well as in low-cost housing and the papermaking industry, as they are all hard cellulosic fibres. For their high tensile modulus and low deformation upon break, these fibres can be classified as hard fibres [23]. Natural fibres have been the subject of several attempts by scientists and technologists to incorporate them into composites. According to the findings of this study, they exhibit great fracture resistance and good electrical, chemical, thermal, and acoustic insulating characteristics. Cellulose fibres have been used as a cheap, renewable, and ecologically beneficial reinforcement material because of the growing interest in environmentally friendly products [24]. Natural fibres are an attractive alternate to artificial or petrochemical-based fibres because of their inexpensive cost, lighter weight, and lower density.

Abaca is a potential natural fibre reinforcing material since it is both affordable and widely available. Fibres by the pseudostem of the banana plant, sometimes referred to as banana fibres or abaca, have intermediate tensile qualities [25]. Fibrous plants, like as abaca, are common in tropical areas and can be grown as a crop. Currently, abaca fibre is a byproduct of banana farming. There is therefore no additional cost to obtain industrial-grade abaca fibre. [26] Creative use of AF during fortification for curbside automobiles has sparked interest in abaca fibre-reinforced composites recently. Acaba fibre is said to have a high strength-to-rot ratio and has a particular flexural strength that is comparable to glass fibres. In abaca fibre, a number of factors must be considered while designing natural fibre composites. Environmental factors like humidity, sunshine, or bacteria can degrade composites, which is a major concern. Fibres' low resistance to water absorption may have a negative impact on the effective stress transmission from the matrix to a fibre [27]. Due to the importance of understanding the long-term impacts of natural fibre composite water absorption and the durability of composites aged in water, it is imperative that this behaviour be thoroughly investigated.

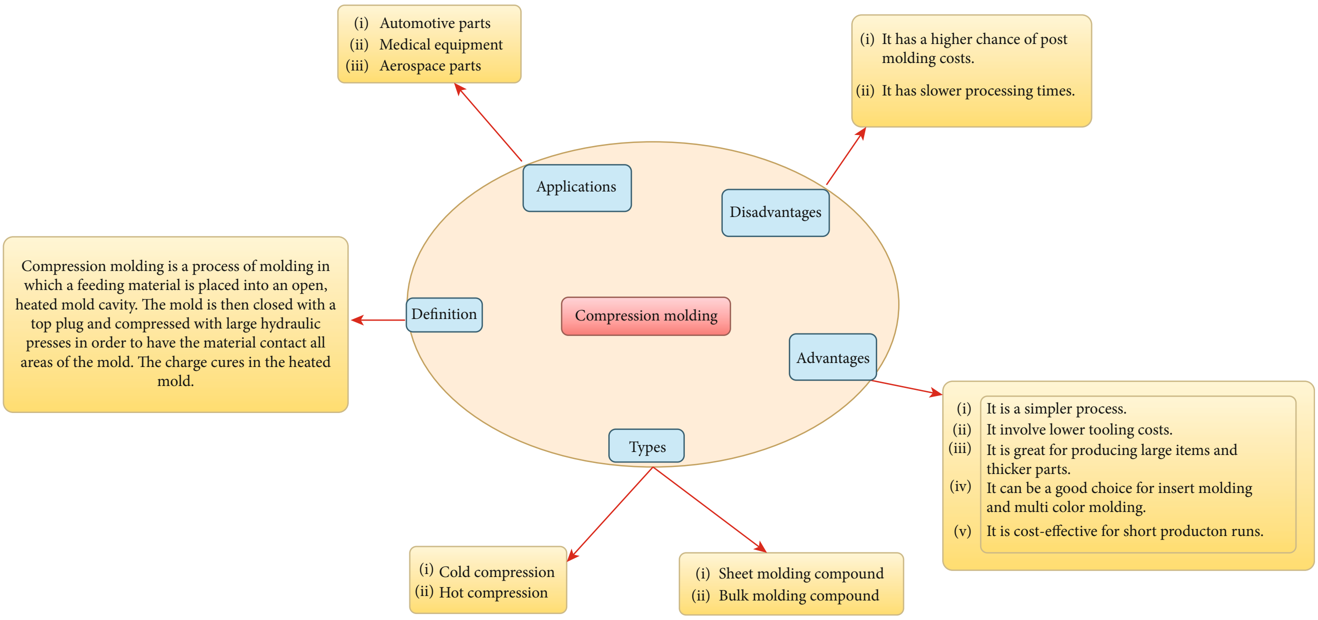

Figure 1: Advantages and application of compression moulding.

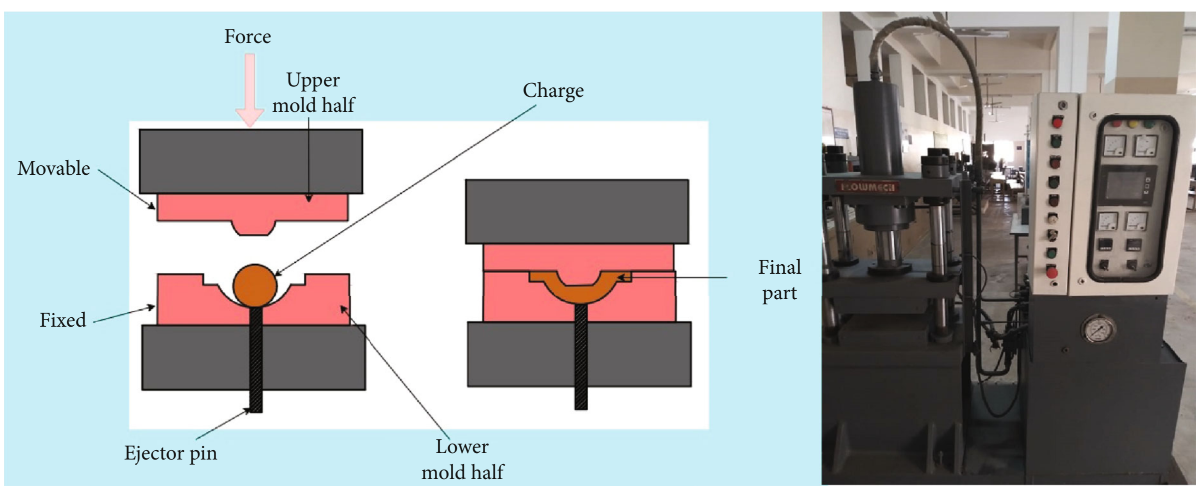

Figure 2: Compression moulding setup.

Because natural fibres are hydrophilic, their inter particle adherence to the polymer matrix is limited, their potential as reinforcing agents is often restricted; chemical modifications are researched to optimise the fibre interface. As a result of chemical changes to fibres, moisture absorption can be reduced [28]. For example, fibres can be treated with alkali or other alkaline agents to lower the moisture absorbed by the fibres. Alkali-treated composites offer improved stiffness, strength, and dynamic flexural modulus, indicating that the matrix and fibres' interfacial bond strength and adhesion have improved. Impurities in natural fibres, such as lignin and pectin, are thought to hinder the fibres' adherence to the matrix during composite construction [29]. In order to improve the interfacial adhesion between the resin and the fibre, natural fibres are routinely treated. Using alkaline treatment to promote fibre adhesion is the cheapest approach, but it reduces fibre strength during treatment, which is a disadvantage.

The water absorption studies of a single abaca fibre are currently unknown. Fibres can be used more effectively in composite materials if we better understand their ability to absorb moisture [30]. Thus, our aim is to study about abaca fibre in detail to see how alkali treatment affected its moisture absorption property in the present work. Figure 1 reveals the advantages and application of compression moulding.

2. Materials and Methods

2.1. Materials. Particles of impact polyethylene are in powder form (250 m). AF was generated in this work using a new extraction method. Fibres were extracted by

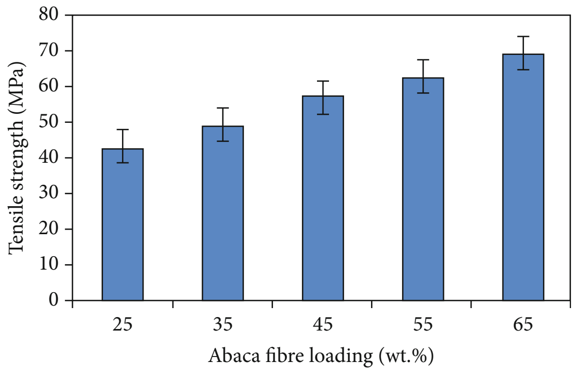

Figure 3: Tensile strength (MPa) vs abaca fibre loading (wt %).

Table 1: The specimens' tensile strength.

Loading of abaca fibre (wt %)	Tensile strength (σ)	Young's modulus ($\boldsymbol{E}$)	Strain ($\boldsymbol{\varepsilon}$)
0	16.1	0.81	0.06
25	43.4	3.10	0.04
35	49.5	3.51	0.045
45	57.1	4.02	0.042
55	62.7	5.12	0.04
65	69.3	3.28	0.06

introducing the abaca into an AFM and let it to spin. Instead of crushing the abaca to remove the waxy covering, this machine employed blades to remove it. Alkaline treatment is a chemical process in which natural fibres are submerged in a high concentration of aqueous sodium hydroxide to cause significant swelling and subsequent changes in fine structure, dimension, and mechanical characteristics over time at a certain temperature. The fibres were alkaline treated after extraction in order to alter their surface properties. For one hour, the fibres were submerged in a water reservoir filled with a 5 percent NaOH solution at room temperature. Before drying at ambient temperature for 48 hours, fibres were splashed several periods in purified water. The tensile strength of fibres can be improved, impurities removed, molecular orientation stabilised, fibre surface treated, and the adhesion among hydrophilic AF and hydrophobic PE improved by undergoing alkaline treatment.

2.2. Composite Preparation. Compression moulding was used to create a composite sheet from several AF/PE composites that were created using a manual mixing process. The purpose of high impact polyethylene is to make the products more immune to impact. To ensure that the samples could be easily removed from the mould after pressing, the mould was initially cleansed with wax. The first step in making composite samples is placing the AF and PE mixture in a mould to guarantee that the fibres are oriented in the same direction. In order to create this 3 mm thick sheet, the compound was heated to 190°C for 5 min and 3.5 MPa for 7 min, after preheating at the same temperature. Using a Proxxon saw, the composites were cut into sheets and then cooled for 30 minutes before being tested in accordance with the ASTM standard.

2.3. Analysis of Mechanical Characteristics. An D3039ASTM Standard is used for tensile properties of polymer matrix composite materials. An UTM setup with a constant head speed test speed of 2 minutes per millimetre evaluated the materials with specifications of 140 mm long, 13 mm in width, and 3 mm in depth. The specimen was held in place in the testing machine's grips, and a hydraulic force was applied until it ruptured. The stress–strain curve diagram was used to determine the tensile stress and elongation %. The density of a substance is an assessment about how densely it is packed up. A digital electronic densimeter was used to determine the AF/PE composite's density. Hardness may be described as a measure of the substance's plastic deformation under the impact of external force. An electronic Shore scale "D" type durometer was used to measure the AF/PE composite's hardness in accordance with ASTM D1957, the standard. Using a dial indicator, we were able to determine the samples' hardness by measuring the depth of the indentation. At least 12 mm away from the sample's edge, perform this hardness measurement to avoid biasing the results. Figure 2 reveals the compression moulding setup.

3. Results and Discussion

Figure 3 depicts the tensile characteristics of the AF/PE specimens in the longitudinal path with varied AF loadings. As a standard error bar, each bar in the graph indicates that the obtained number falls within an acceptable range. AF loading has a significant effect on the composites' behaviour. In order to attain a tensile strength of 72 MPa, 65 percent of the AF loading was required. Additions of 25 and 65 percent fibre increased tensile strength by 168 and 354 percentage points, respectively, compared to ordinary polyethylene (PE) and polypropylene (PP), respectively. Compared to other natural composites, the rate of growth is consistent. Research using various cultivars by other scientists has yielded lower tensile strength findings than those achieved here. The composite tested by [6] had tensile strengths of 30–38 MPa in unidirectional orientation AF. The greater tensile strength achieved in this study can be attributed to the characteristics of AF and the effect of alkaline treatment on its surface. In other words, when the AF is parallel to the tensile axis, it is more effective.

Table 1 shows that the maximum tensile strength and strain values were found with an AF loading of 65 wt percent. This is due to the fact that increased fibre loading will increase the composite's strength. Due to the matrix's role in transferring forces to the fibres, a higher fibre loading allows for greater force resistance than a lower fibre content would. It was mixed with a fine powder of polyethylene (PE) (250 micrometres in diameter) during the fabrication of the samples, which resulted in composites. As a result of this, there is a higher degree of fibre-to-matrix attachment. [24] said that strong fibre-matrix adhesion enables stress transfer from the specimen to the fibres, hence increasing the composite's structural characteristics. Due to the increased tensile

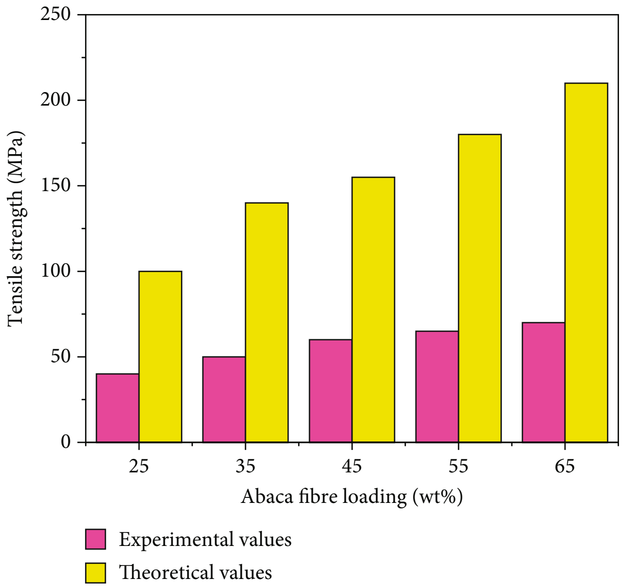

Figure 4: Tensile strength (MPa) vs abaca fibre loading comparison between experimental and theoretical results (wt percent).

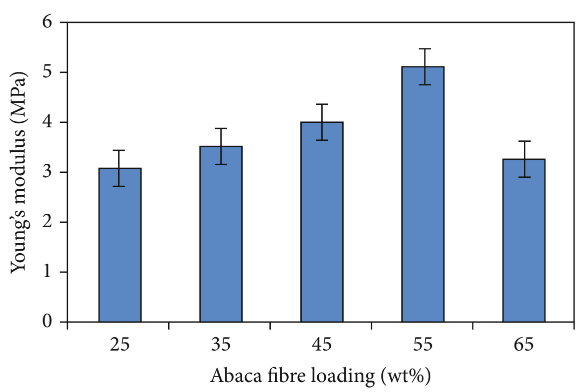

Figure 5: Young's modulus (GPa) vs abaca fibre loading (wt %).

strength brought about by fibre content, the strain characteristics of the material will naturally be reduced. However, the results of this experiment reveal that inclusion of fibre contented enhances strain characteristics, as given in Table 1. More alkaline-treated fibres will therefore boost the composite's strain characteristics, and the AF and PE's high adhesive bonding has evolved because the PE is in precipitate form.

The consequences of the practical and theoretical tensile strength tests were compared using the rule of mixture formula, and the results are shown in Figure 4. The law of combination was utilized to compute the tensile toughness in the longitudinal direction as given in Equation (1). By employing the equation, we were able to determine the volume fraction of fibre relative to matrix (2).

$$\sigma_c = \sigma_m V_m + \sigma_f V_f, \quad (1)$$

$$V_m + V_f = 1, \quad (2)$$

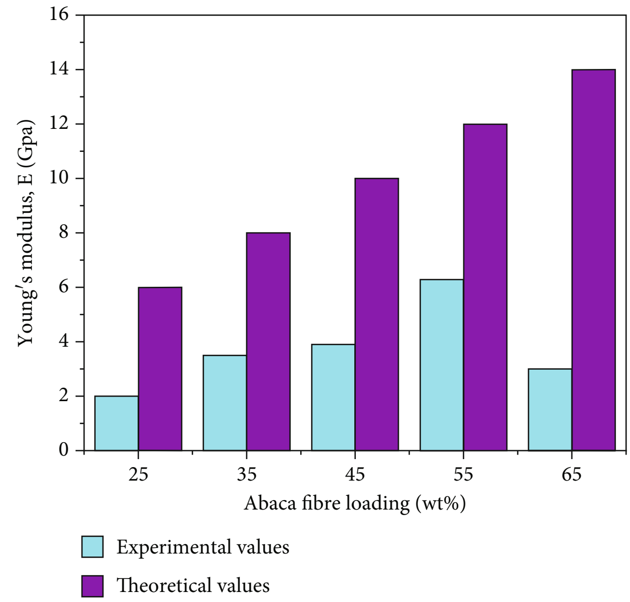

Figure 6: Experimental and theoretical comparison of Young's modulus (GPa) with the loading of the abaca fibre (wt percent).

where σc = composite tensile strength, σm = matrix tensile strength, σf = fibre tensile strength, Vm = proportion of a matrix's volume, and Vf = %volume portion of fibres.

A comparison of actual and theoretical data shows that when AF loading increases, tensile strength increases as well. The experimental results, on the other hand, are lower than expected. Fibres may have been misaligned, and composites may have been improperly produced. Figure 5 depicts the longitudinal Young's modulus of the AF/PE composite under various AF loading conditions. Young's modulus increases with AF loading except at 65 wt percent, as shown in the graph. A 538 percent rise in the Young's modulus of plain PE and a 37 percent decrease in the Young's modulus of 65 percent fibre. The better adhesion between the fibres and the matrix was found to be the cause of the composite's increased Young's modulus.

Figure 6 contrasts the theoretically and experimentally results for the Young's modulus with AF loading. This equation can possibly be used to compute the Young's modulus (3).

$$E_c = E_m V_m + E_f V_f. \quad (3)$$

Figure 7 depicts the Shore-D and density (g/cm3) curves for the longitudinal AF/PE composite based on AF loading. As AF loading is increased, hardness and density both rise. When compared to plain PE, the hardness and density rise by 0.53 percent and 6.93 percent, respectively, when 25 weight percent fibre is added. When AF loading is increased by a factor of up to 65 weight percent, the result is comparable to when the AF loading is increased by a factor of 25 weight percent. Other natural composites are also seeing a rise in popularity. There is a strong correlation between fibre inclusion and composite hardness, according to [28]. The

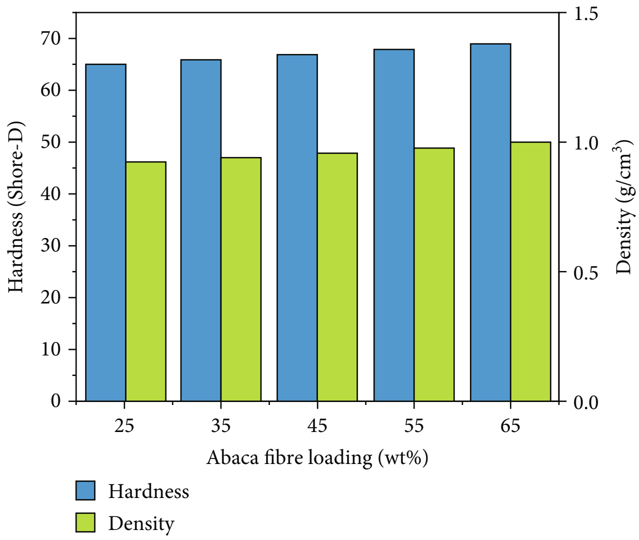

Figure 7: Surface hardness and mass density (g/cm^3) (wt %).

composite's toughness and strength are directly correlated to the material's abrasion resistance. Due to the fibres' tight packing, the composite's density has increased as the content of fibres has raised. Increasing the AF loading in AF/PE composite increased its resistance to indentation, which led to a rise in the composite's density as well.

4. Conclusion

Abaca fibres treated with alkaline have an effect on the mechanical properties of composites and also fibre loading affects the mechanical characteristics of an impact polyethylene composite, and this study has shown to be true. 65/35 AF/PE composites have the best mechanical qualities of the other component ratios (25/75, 35/65, 45/55, and 55/45), with a tensile strength of 69.3 MPa with Young's modulus increases with AF loading except at 65 wt percent and a hardness of 67.52 Shore-D, respectively. Hardness and density both increase as AF loading is increased. As 25 weight percent fibre is added to plain PE, the hardness and density increase by 0.53 percent and 6.93 percent, respectively. When AF loading is raised by up to 65 percent, the effect is equivalent to when AF loading is increased by 25 percent. Uneven fibre distribution has been found to have an effect on the mechanical characteristics of composites made from AF/PE. In order to improve the adhesion between the AF and PE, we intend to add maleic-anhydride-grafted polyethylene or polylactide to dispersion of fibres during the fabrication process.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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