Mechanical Characterization, Biodegradability Evaluation, and Machine Learning-based Prediction of Bio-composites Fabricated from Polybutylene Succinate (PBS) and Cow Dung Powder

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Mechanical Characterization, Biodegradability Evaluation, and Machine Learning-based Prediction of Bio-composites Fabricated from Polybutylene Succinate (PBS) and Cow Dung Powder

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Abstract: The objective of present research was to devise a biocomposite material by analyzing different existing biocomposites enhancing the machining performance focusing on wrenching using a machine-learning methods. In this study, polylactide/cow dung powder biocomposites with 0-20 wt% CDP and ball milling were used to study the physical, mechanical and biodegrade properties of the polylactide biopolymer. The maximum density and mechanical strength observed was in biocomposite having 20% CDP powder. Ten weight percent CDPs contained biocomposite performance ranges critical tensile strength as 22.2 MPa for a particle size of 250 µm and 21.1 MPa for 500 µm. The melt flow index (MFI) increased as the CDP content raised to 5% but decreased with higher CDP percentages within a range of 34.6 to 55.7 g/10 min for 250 µm particles and 30 to 55.7 g/10 min for the 500 µm particles. CDP powder in biocomposite at 5% had the highest melt flow index while at 20% CDP showed the lowest MFI (melt flow index). And for those biocomposites performance ranges for crash there was a decrease in the impact strength value with increasing CDP content, with a range of 4.2 to 2.1 kJ/m2 for the 250 µm particles and 4.2 to 2.5 kJ/m2 for the coarse 500 µm particles.

The more the CDP content, the greater the water absorption and it was observed to be the highest at 3.85% for the use of 20 wt% CDP with size 500 µm. The biodegradation studies showed that the weight loss of biocomposites was directly proportional to the CDP content, and the maximum weight loss of 5.6 % for 20 wt% CDP biocomposite was observed after 50 days in soil. It was also shown that the addition of CDP to PBS increases the biodegradability of the materials, though it has an impact on mechanical properties and processability, which can be beneficial for biocomposite applications. The research conducts performance prediction and optimization of a PBS/CDP biocomposite material. The efficiency of different ML methods wherein Extra Trees, Decision Tree and AdaBoost are among the best. In present study the prediction of the properties like density, impact energy and bio degradability of the composite were analysis using ML methods and the best R^2 for the density were found in DT, XT, random forest and ada boost ML method. The best R^2 for the impact energy was found in DT, XT, adaboost and random forest ML method. The Best R^2 for the biodegradability properties was found in XT machine learning method for the present study.

Keywords: Poly butylene-succinate (PBS); Cow Dung Powder; Bio-Composite; machine Learning; Drilling Operation; Wear Analysis

1. Introduction

As technology reaches new heights, more and more researchers try to use modern materials that not only have a special purpose, but also do not harm the environment[1,2,3,4)].

Polymer biocomposites was reviewed as the combination of a biopolymer matrix and a biodegradable filler. Polymer biocomposites have recently emerged as a class of materials that combine the rigidity of a polymer matrix and the biodegradability in composite. This leads to materials having properties which were not found in either component individually, and its rising interest is due to its cost and environmental benefits. Antimicrobial solvable biocomposites could be fabricated from a biodegradable polymer, plant fibre and waste of bio-industrial materials, which may lead to the 63to opportunities of making use of waste that would either be landfilled or incinerated and lowering the amount of plastic used[5,6,7,8].

PBS was polyester that have good biodegradable properties with maintain the other important properties like strength, water absorption, thermal properties and many others. It has high processability, heat transfer characteristics, strength, compressive properties and biocompatibility. Due to these properties, PBS can be expected to be applied in many commercial fields further. Moreover, PBS is a non-toxic material and does not pose health hazards in many uses including the medical sector and food packaging materials[9,10,11,12].

Biocomposites, made of compostable polymers and agricultural residue or natural fibers, have been of interest due to their economic and environmental benefits. These products involve bio-based and biodegradable materials, plant fiber and agricultural industrial waste. Previous studies concluded that the biocomposites developed from agriculture or forestry waste may help towards the elimination of buried or incinerated waste and diminishing plastic engagement. It has too been demonstrated in this study that these composite materials are capable of minimizing the wastes dumped in landfills or incinerated and decreasing plastic usage[13,14,15,16].

One type of biopolymer that has shown promise in the development of biocomposites is PBS specially mixed with waste natural fiber material like agricultural waste, dairy waste. PBS mixed biocomposite show various promising properties required for industrial applications can make this material for research investigation and industrial level development. These physical. Mechanical and chemical properties make PBS a promising base material to fabricate the biocomposite for a wide range of commercial applications, including the biomedical industry and the packaging of food products. However, the high cost of PBS may limit its use in some industrial applications[17,18,19,20].

To solve this problem, PBS composite has been targeted with natural fibers in the mixture aiming at cost reduction while making use of green materials. Almond flour, rice husk, wheat straw, bamboo fiber, jute fiber, sugarcane residue are examples of agro-waste and are preferred materials because they are cheap, readily available, low in density, renewable & sustainable, biocompatible and eco-friendly. Blending natural fibers with PBS would improve the mechanical, thermal, and tribological characteristics of the composites produced. In the last ten years, the supply of PBS materials has enhanced remarkably and as a result, more studies have focused on the creation of biodegradable composites with a mixture of PBS and natural fibers[21,22,23,24,25,26].

In recent years, there has been a significant amount of research on the use of natural fibers as reinforcements in polymer biocomposites. Liminana et al. (2018)[27] investigated the effect of incorporating almond shell flour on the mechanical properties of polymer (butylene succinate) composites. In this study the researcher investigates on the biocomposite and found that the mixing of almond shell flour powder upto 30% by weight was show the increment in tensile strength. Some other properties like tensile strength were also increased but elongation was decreased due to high level of natural powder in biocomposite. Huang et al.[28] fabricated the biocomposite made by natural fiber of sugarcane and PBS as base material. In this study the researcher observed that by mixing of the sugarcane powder in biocomposite improve the biodegradability of the composite up to 5%.

Jittiwat & Namfon (2022)[29] examined the influence of cassava pulp on the mechanical properties of PBS-based biocomposites. They found that increasing the amount of cassava pulp in the biocomposites reduced the tensile strength, impact strength, and elongation at break, but increased the hardness and strength parameters of the biocomposites.

Other research has focused on the use of specific natural fibers, such as rice husk and date palm fiber waste, in biocomposites. Yap et al.[25] investigated composite materials made with PBS/PBAT and rice husk fillers. In this study the researcher investigates that by mixing the natural fiber powder in composite decrease the strength properties but improve the biodegradable properties. They analysis that the decrement in strength was low with compare the base composite materials so the mixing of the natural fiber powder can be used for making the biocomposite. Total 90% biodegradable results were observed in this study. Dhakal et al. (2018)[30] reported that polycaprolactone biocomposites with 20% date palm fiber waste exhibited higher tensile modulus and strength, but at the expense of reduced tensile strength and toughness. Andrzejewski et al. (2019)[31] found that the addition of wood waste to PLA and polypropylene-based composites increased the tensile modulus, but decreased tensile strength and toughness, particularly at wood content above 20%. These findings demonstrate the potential trade-offs that may occur when incorporating natural fibers into polymer biocomposites.

It is widely acknowledged that the natural/basalt fabric mechanical properties were determined by several interrelated factors, including the morphological properties and content of filler and processing conditions, and the dispersion characteristics of the natural fiber used. Thus, these properties were frequently taken into account by the scholars when choosing a natural fiber material for biocomposite applications[32].

Biocomposite made by using agricultural waste specially in powder form was used in large scale by research and industrial communities in past some years due to the effective properties of these bio waste materials.

The most of the properties of these natural materials were good for making the biocomposite and reported in various published literature material. The common natural waste materials were like plant fiber, agricultural waste, animal waste like cow dung, and other type of wastages from food processing industries. Additionally, the use of agro-waste in biocomposites can provide economic and environmental benefits, as it can help to reduce the amount of waste sent to landfills and decrease the reliance on petroleum-based materials[33,34,35,36)]. Previous research has demonstrated that different biocomposites can exhibit unique performance characteristics that are suitable for a variety of applications. As a result, it is important to develop alternative biocomposites made from natural ingredients that are optimized for various performance characteristics. Machine learning techniques can be employed to identify the optimal biocomposite material for specific applications and address issues related to the properties of biocomposites. By using machine learning techniques, it is possible to identify the most suitable biocomposite material for a given application and optimize its performance characteristics. This can be especially useful in situations where multiple performance criteria need to be considered simultaneously[37,38,39,40)].

Application of cow dung powder in composite fabrication makes the composite stronger and better than normal composite[66,67)]. Cow dung powder make the composite stronger due to its fiber properties and better thermal properties[68,69,70)]. India was known for animal husbandry in rural area and the cow dung production was very high in India. There was various use of cow dung powder in agricultural applications but very less use in other applications like for making the bio composite and the reason behind this study was to use the cow dung powder was the same and it was also the research gap for the present study.

Machine learning methods play important role for prediction of properties of the composites like mechanical, physical chemical and other properties. ML methods have been proved for composite prediction specially regression-based ML merhods[71,72,73)].

2. Materials

During the experiment, a commercial injection grade of neat unused PBS (B3C03) obtained from local provider from Gujarat, India was utilized as the matrix material. This grade has a melting temperature range of 120-200°C[46)] and a density of 1.25-1.50 g/cm3[46)], and exhibits a melt flow rate of 5 g/10 min when heated to 120°C with a weight of 2.0 kg. The cow dung powder waste used in the experiment was sourced from Kalyan Milk and Agro Products, a local cow dairy business in the Indian state of Rajasthan. Figures 1a and 1b provide macroscopic and microscopic views of the material, respectively. Before being incorporated into PBS-based materials, the cow dung waste particles underwent alkali treatment using a 2% sodium hydroxide solution[45)]. Both the waste PBS and cow manure were then dried in a Techzere Electric Dehumidifier at a temperature of 80°C for 15 hours[45,46)] to make them dry in nature. This was the first step in the production process. Subsequently, CDP particles with sizes ranging from 250 μm to 500 μm were mixed with melted PBS matrix particles at a maximum CDP content of 20%. The cow dung powder was individually sieved to obtain particles within this size range using 40 mesh and 60 mesh sieves, which were commercially available.

Fig. 1: Cow dung powder (CDP)

In the present study, the Melt Flow Index (MFI) was measured according to the ASTM D 1238 international standard[41)]. In present investigation, the MFI was measured by using the MFI-421/16 manufactured by PSI Sales Pvt Ltd, New Delhi, India. The experiment was set for 150C. The reported value of the MFI was the average of three separate measurements of each mix id of the biocomposite.

3. Method

In present study the fabrication of the biocomposite was stated to dry out the PBS pellets by using the hot oven, in which the air was circulated on 80°C[45,46)] temperature. The same dry process was carried out for CDP powder. The drying process was carried out for 15 hours.

To create a range of PBS to CDP weight ratios, CDP particles of varying sizes with diameters ranging from 250 μm to 500 μm were used to make composites, starting from a ratio of PBS100CDP0 and ending at a ratio of PBS80CDP20. The CDP powder was mixed using ball milling machine for two different sizes (250 and 500 μm). To make the biocomposite the proper mixing of the PBS and CDP powder was performed using the twin-screw extruder machine in the hot environment (temperature was maintain to 150°C). The suitable RPM of the extruder was maintained to 50 RPM for optimum mixing of the PBS and CDP powder. In order to create biocomposite plates, the samples were compressed using a hand-operated injection machine for two minutes at a temperature of 150°C and a pressure of 5 MPa. The injection rate used to make the biocomposite was in the range of 20 cm3/s to 50 cm3/s[47)].

4. Composite Characterizations

4.1 Mechanical Testing

Tensile strength and Young's modulus were measured according to the standard ASTM D638[42]. To measure the tensile strength and other mechanical properties of the biocomposite UTM machine was selected installed at college (Amity University, Jaipur) laboratory. To measure the proper load, load cell was used with digital indicator. The load cell used in this UTM machine was capable to measure the 20 kN load with high accuracy level. The test specimens were made according to the dimensions specified in the standard, with a total length of 115 mm, a thickness of 3.2 mm, and a middle length of 33 mm in the shape of dumbbells.

The impact strength of the 4iocomposite made in this study was also tested using Izod impact testing machine as per ASTM D256 international standard[43]. The impact test was carried out at room temperature. The test was carried out using a pendulum impact tester. In the present study, hardness was measured for the PBS/CDP composites according to the ASTM D 2240[44] international standard. The Shore D hardness value was determined using specimens of 63.5 mm and 3.2 mm thick as per standard requirement.

4.2 Biodegradability Properties

In current study the biocomposite made by suing PBS and CDP powder with different mix combinations. To test the biodegradability properties of the biocomposite the rectangular objects (50mm by 10mm by 2mm thick) were fabricated. All different specimens as per mix combinations of the biocomposite (100PBS0CDP ~80PBS20CDP). The testing method developed by Kim et al.[48] was used to test the biodegradability of the fabricated specimens. In this study the specimens were buried in soil for 50 days. The specimens were kept in plastic container filled with soil and buried in 30 cm below the ground level as per testing standard.

After being buried for the following lengths of time: 0, 7, 15, 25, 30, 40, and 50 days[48], the specimens were excavated and washed with distilled water before being dried in an oven with hot air at a temperature of 50 C for one day. The percentage of weight loss was then calculated using a digital scale and the final result was determined using the following equation:

$$BioComp_{Wt.Loss} = \frac{Wt_{initial} - Wt_{last}}{Wt_{intial}} * 100 \quad (1)$$

Where initial and last represents the initial day and final day of the composite buried in the soil for the testing.

4.3 Composite Density and Water Absorption Properties

Fabricated biocomposite made by PBS and CDP powder (100PBS0CDP ~80PBS20CDP) was investigated for density and water absorption properties. To measure the density, the gravimetric method was used. Total 10 samples were fabricated for each mix combinations of CDP powder (250 µm and 500 µm). Each sample were measured by digital weighing machine. To test the water absorption of the biocomposite, each dry tested specimen was merged into the water filled in biker and replaced by weight equal to test specimen and measure the weight as per test requirement. The formula used for calculate the water absorption was shown in equation 2.

$$BioComp_{water-Abs} = \frac{W_{final} - W_{initial}}{W_{initial}} * 100 \quad (2)$$

The weight of each sample (Wt) was recorded, and the volume of water absorbed was calculated using formula for all test specimens of the biocomposites.

5. Machine Learning Approach

Machine learning (ML) has emerged as a powerful tool in optimizing machining operations for various materials. In recent years, researchers have focused on using ML techniques to optimize machining of biocomposites, which are gaining popularity due to their eco-friendliness and biodegradability. One such biocomposite is made with poly butylene-succinate (PBS) and cow dung powder (CDP). In a study by A. Fertig et al[62], the authors developed a hybrid ML model to optimize the milling operation using machining dataset. The model combined the response surface methodology (RSM) with nine machine learning models like CNN, SVM, DT, KNN, GNB to predict the optimal combination of machining parameters such as cutting speed, feed rate, tool design parameters etc. The detailed research flow of the machine learning based study was show in the figure 2, as seen in figure 2, the all-input requirement for the ML based study was presented like input, target properties, testing validation and all relevant information required for the ML based study. The results showed that the hybrid model achieved a higher accuracy in predicting the optimal parameters compared to the linear regression model alone.

Similarly, in a study by Schorr et al.[63], the authors used the Taguchi-based response surface method (TRSM) and an ANN model to optimize the turning parameters of a PBS/CDP biocomposite. The study aimed to minimize the surface roughness and tool wear rate while maximizing the material removal rate. The results showed that the optimized parameters obtained through the ANN model were more accurate than those obtained through the TRSM method alone. Various authors[64,65] developed a prediction model for the surface roughness and cutting force of the composite for machining operations using machine learning model. The study optimized the drilling parameters such as spindle speed, feed rate, and drill bit diameter. The results showed that the developed ANN model could predict the surface roughness and cutting force of the biocomposite with a high degree of accuracy.

In this research work, researchers have employed a range of machine learning models to analyze and predict biodegradability and other properties of the material under study. The research flow diagram used in preset study was shown in Fig. 2. The models used in this research are:

Random Forest (RF): An ensemble learning technique that constructs multiple decision trees during training and averages their predictions. Random Forests offer robustness against overfitting and can handle a large number of features.

Linear Regression (LR): A simple yet effective model that establishes a linear relationship between input features and target variable(s). It is easy to interpret and computationally efficient.

Support Vector Regression (SVR): A model that extends the Support Vector Machine (SVM) algorithm to handle regression tasks. SVR attempts to find the optimal hyperplane that fits the data points with minimum error, providing strong generalization capability.

K-Nearest Neighbors (KNN): A non-parametric, instance-based learning algorithm that predicts the target variable by averaging the values of its k-nearest neighbors in the feature space.

Ridge Regression: A variant of Linear Regression that introduces L2 regularization to prevent overfitting and reduce model complexity.

Decision Tree (DT): A tree-based model that recursively partitions the feature space to make predictions. Decision Trees are interpretable and can handle non-linear relationships, but they are prone to overfitting.

Extra Trees (XT): An ensemble learning method similar to Random Forest, but with a different tree construction process. It uses randomized decision trees and averages their predictions, providing better generalization capability and lower variance.

AdaBoost (Adaptive Boosting): An ensemble learning algorithm that combines multiple weak learners (typically Decision Trees) to build a strong learner. AdaBoost iteratively adjusts the weights of the weak learners, focusing more on the misclassified instances to improve the overall model's performance.

Each machine learning model has its own set of input parameters (also known as hyperparameters) that control the model's behavior and learning process. Here's a list of input parameters for the models used in the code and present in table 1.

Table 1. ML Mode Algorithms and Hyper parameters used in present stud

Model	Hyper parameter	Default Value
"Random Forest Regressor"	"n_estimators"	150
	"criterion"	"MSE"
	"max_depth	None
	"min_samples_split"	4
	"min_samples_leaf"	1.3
	"random_state"	NA
"Linear Regression"	"fit_intercept"	TRUE
	"normalize"	FALSE
SVM Regression Method	"kernel"	"RBF"
	"degree"	5
	"gamma"	"scale"
	C	1.3
	"epsilon"	0.14
"Kneighbors Regressor"	"n_neighbors"	5.3
	"weights"	"uniform"
	"algorithm"	"auto"
	"leaf_size"	35
"Ridge Regression Method"	"alpha"	1.1
	"fit_intercept"	TRUE
	"normalize"	FALSE
"Decision Tree Regressor"	"criterion"	"MSE"
	"splitter"	"best"
	"max_depth"	NA
	"min_samples_split"	4
	"min_samples_leaf"	2
"Extra Trees Regressor"	"n_estimators"	150
	"criterion"	"MSE"
	"max_depth"	NA
	"min_samples_split"	10
	"min_samples_leaf"	5
	"random_state"	NA
"Ada Boost Regressor"	"base_estimator"	NA
	"n_estimators"	65

Fig. 2: Research Flow steps for ML prediction model

6. Result and Discussion

6.1 Melt Flow Index

The melt flow index (MFI) of PBS/CDP biocomposites with CDP particle sizes of 250 and 500 µm was found to be in the range of 34.6-55.7 g/10 minutes. For biocomposites containing CDP particle sizes (500 µm) of 29.4-55.7 g/10 minutes, the MFI was found to be in a different range. The MFI for plain PBS was the highest among all of the PBS/CDP biocomposites, at 55.7 g/10 minutes. The MFI decreased significantly as the concentration of CDP in the biocomposites increased, and this was observed for both particle sizes of CDP. In addition, the MFI was higher when 250 µm CDP was used in PBS95/CDP5 compared to 500 µm CDP. Other compositions of PBS/CDP biocomposites showed more resistance to the MFI. The minimum MFI was observed when CDP was mixed up to 20% in the PBS matrix, and this value was equal to 30 g/10 minutes for 500 µm CDP particle size.

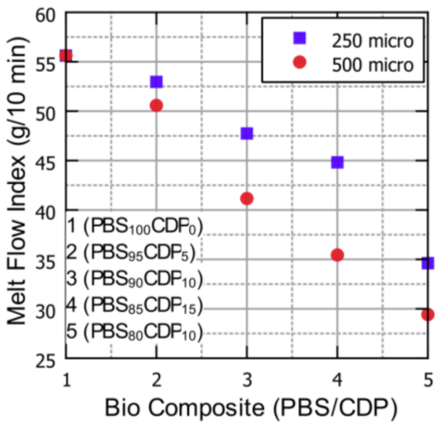


Fig. 3: MFI for Bio Composite (PBS/CDP) for two particle sizes (250 µm and 500 µm)

The smaller size CDP particles exhibited a higher level of homogeneity and compatibility within the polymer matrix[45,46], as demonstrated by their more even distribution. This was supported by the results of the melt flow index test, which showed that the PBS80/CDP20 sample with 500 µm particles had a minimum MFI of 26 g/10 min, significantly lower than that of pure PBS material. This difference can be attributed to the mixing of CDP particles, which enhanced the discontinuous mixing of both PBS and CDP particles in the composite.

6.2 Mechanical Properties

The tensile strength and Young's modulus of the PBS/CDP biocomposites are shown in Figure 4 and Table 2. These mechanical properties were observed in the biocomposites. In contrast, the pure PBS exhibited a tensile strength at break of 27.1 Mpa, a significant increase from the previous value. When the particle size was reduced to 250 µm, the tensile strength of the PBS/CDP biocomposites ranged from 18.9 Mpa to 25.4 Mpa, with a CDP content ranging from 10% to 20% of the total mass.

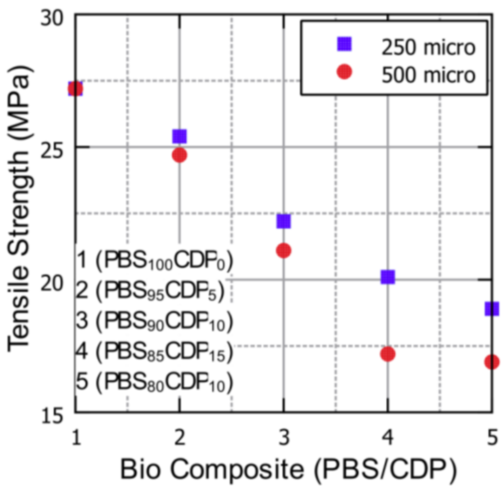
Table 2. Tensile Strength and Young Modulus of the Bio Composite

Mechanical Properties (250 µm)			
PBS %	**CDP %**	**TS**	**YM**
100	**0**	27.2	1052.2
95	**5**	25.4	921.4
90	**10**	22.2	845.1
85	**15**	20.1	981.3
80	**20**	18.9	1068.5
Mechanical Properties (500 µm)			
PBS %	**CDP %**	**TS**	**YM**
100	**0**	27.2	1052.2
95	**5**	24.7	929.4
90	**10**	21.1	961.2
85	**15**	17.2	993.5
80	**20**	16.9	1074.8

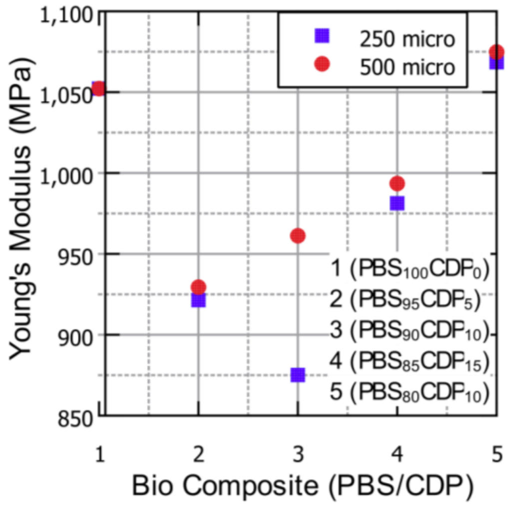
TS (Mpa), YM (Mpa)

After investigation on strength properties like tensile strength and impact strength it was observed that by mining the CDP powder in PBS made composite, reduce these strength properties as seen in table 2. The decrement was observed for both 250 µm and 500 µm CDP powder made biocomposite.

This led researchers to conclude that pure PBS had superior stiffness and strength compared to PBS/CDP biocomposites. The possible reason of this reduce values in strength properties was the stiff interface among powder materials and matrix materials in composite specimens, it was more verified by making the fracture specimens microstructure analysis which make the proof for the investigation. This could be because a stiffer interface allows for less deformation of the fibers and matrix[50,51,52]. This effect was observed when the CDP content was increased.



(a)



(b)

Fig. 4: a) Tensile Strength b) Young Modulus results of PBS/CDP bio composite

The tensile strength of PBS95/CDP5 with a CDP particle size of 250 µm was slightly higher than the tensile strength of PBS95/CDP5 with a CDP particle size of 500 µm. The size of the CDP powder was the key parameter which improve the tensile strength of the composite like the tensile strength and impact energy of the 250 µm powders made biocomposite was much higher then properties of 500 µm powder made biocomposite.

These findings are similar to those presented by Kim et al.[48] in their research on rice husk powder mixed with PBS matrix materials. In their study, Kim observed that reducing the size of the rice husk powder increased the tensile strength of the composite. Similarly, we achieved this result by reducing the size and quantity of cow dung powder (CDP) used in the biocomposites. The Young's modulus of the bio composite increased from 921.4 Mpa to 1068.5 Mpa (250 µm) when more than 10% CDP was added. However, when the particle size was increased to 500 µm, the Young's modulus increased from 929.4 Mpa to 1074.8 Mpa. This increase in the Young's modulus suggests that the incorporation of cow dung powder into the biocomposite was able to significantly increase its stiffness compared to the pure PBS composite. This trend was also observed by researcher[51] in their study on PBS combined with bamboo kraft pulp, likely due to the increased stiffness of the developed composite with the inclusion of natural components.

Impact energy analysis was another important study for biocomposite, in this investigation the measured impact energy for different mix combinations of biocomposite was present in table 3. The results were show in Figure 5. It was observed that the mixing of CDP powder in composite can reduce the impact energy of the composite

The size of the CDP powder was the key parameter which improve the impact energy of the composite like the impact energy of the 250 µm powder made biocomposite was much higher then properties of 500 µm powder made biocomposite.

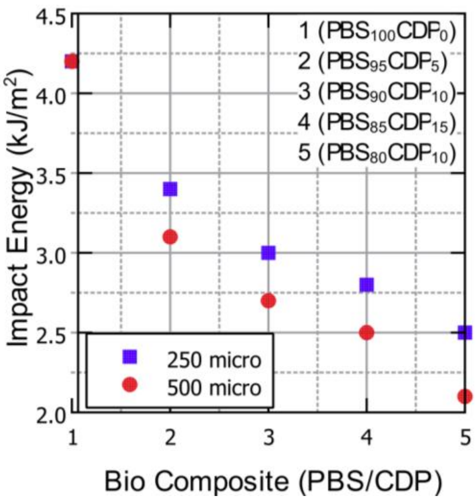
Table 3**.** Impact Energy and Hardness of the Bio Composite

Mechanical Properties (250 µm)			
PBS %	**CDP %**	**IMPACT ENERGY**	**HARDNESS**
100	**0**	4.2	67.2
95	**5**	3.4	67.9
90	**10**	3.0	68.4
85	**15**	2.8	69.1
80	**20**	2.5	70.5
Mechanical Properties (500 µm)			
PBS %	**CDP %**	**IMPACT ENERGY**	**HARDNESS**
100	**0**	4.2	67.2
95	**5**	3.1	68.1
90	**10**	2.7	69.2
85	**15**	2.5	70.3
80	**20**	2.1	71.4

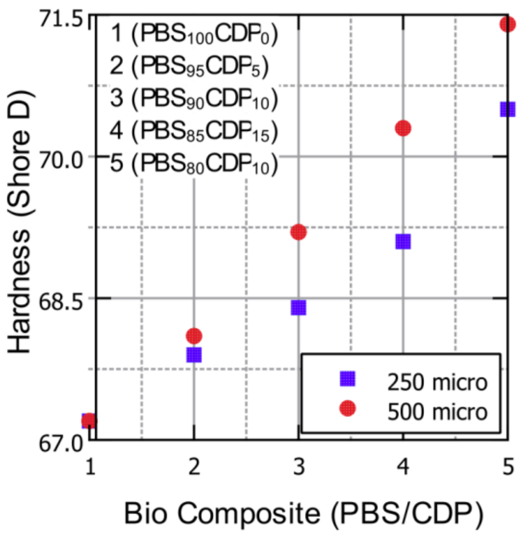
Impact Energy (kJ/m2), Hardness (Shore D)

The impact energy for a particle size of 250 µm ranged from 3.4 kJ/m2 to 2.5 kJ/m2 and the hardness ranged from 67.9 Shore D to 70.5 Shore D. A similar trend was observed for the 500 µm particle size, which ranged from 3.1 kJ/m2 to 2.1 kJ/m2, and the hardness ranged from 68.1 Shore D to 71.4 Shore D. The impact resistance of each PBS/CDP composite was lower compared to the impact resistance of pure PBS. The fracture became more brittle when the concentration of CDP in the biocomposites was increased up to a maximum of 20%. It was found that the impact strength of PBS/CDP composites decreased with an increase in the percentage of CDP present in the test object[54].

There was a correlation between the amount of CDP in the PBS/CDP biocomposites and an increase in the Shore D hardness of the biocomposites, which has also been observed by other researchers working with PBS-like materials. This increase in Shore D hardness was also observed to increase the materials' level of abrasion resistance.



(a)



(b)

Fig. 5: a) Impact Energy b) Hardness results of PBS/CDP bio composite

The shore D hardness of the CDP-based composite with a particle size of more than 250 μm was found to increase, similar to the results observed for YM parameters. This phenomenon was also observed by L. Quiles-Carrillo et al[57] in their study on Poly lactide-based composites. The incorporation of micro natural filler materials into the PBS matrix is believed to contribute to the improvement in composite hardness by strengthening the bond between the particles.

6.3 Density and Water Absorption

Biocomposite density and its water absorption capacity was present in table 4 and show in Figure 6. As seen in table 4, the mix of the CDP powder in composite reduce the density of the biocomposite when compare with neat plastic object made by PBS. The size of the CDP powder was the key parameter which reduce the density of the composite like the density of the 500 micro powder made biocomposite was much lower than properties of 500 micro powder made biocomposite. The water absorption of the bio composite was increased when biocomposite made by CDP powder of size of 500 micro and the highest water absorption capacity was observed for PBS80CDP20 for 500 micro sized powder particles. Utilizing high-pressure injection equipment during the molding process can further increase the density of the composite[58].

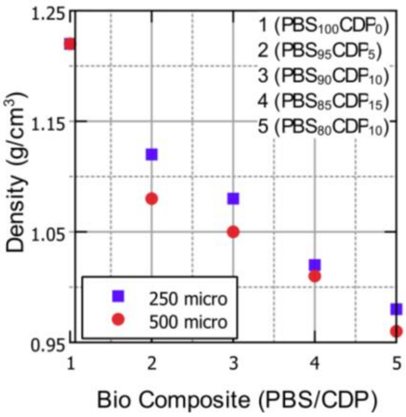
Table 4. Measured Density and Water Absorption of the Bio Composite

Mechanical Properties (250 micro)			
PBS %	**CDP %**	**DENSITY**	**WATER ABSORPTION**
100	**0**	1.22	0.82
95	**5**	1.12	1.35
90	**10**	1.08	2.21
85	**15**	1.02	2.67
80	**20**	0.98	3.43
Mechanical Properties (500 micro)			
PBS %	**CDP %**	**DENSITY**	**WATER ABSORPTION**
100	**0**	1.22	0.82
95	**5**	1.08	1.54
90	**10**	1.05	2.62
85	**15**	1.01	3.28
80	**20**	0.96	3.85

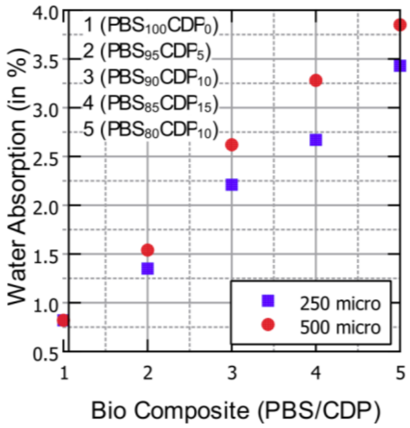
Density (g/cm3), water absorption (in %)

The addition of CDP granules with particle sizes of 250 μm and 500 μm resulted in a significant decrease in the density of the PBS matrix, down to 0.98 g/cm3. The non-uniform molecular alignment of the molten polymer and reinforcing biomass material may be responsible for the formation of gaps within the biocomposites, leading to a decrease in composite density[59].

The water absorption (WA) performa"ce o' PBS/CDP biocomposite samples was evaluated by submerging them in water for 15 days and measuring the difference in weight between the composite and the pure PBS sample. This was done to determine the WA behavior. The pure PBS sample showed a shift of 0.82% in its ultimate weight, but no additional influence was observed on the sample.



(a)



(b)

Fig. 6: a) Measured Density b) Water Absorption results of PBS/CDP bio composite

The crystalline matrix of the sample displayed significant water barrier qualities, which contributed to the overall stability of the pure PBS sample. The 500 µm CDP composite showed a higher water absorption percentage compared to the 250 µm composite (as shown in Table 3).

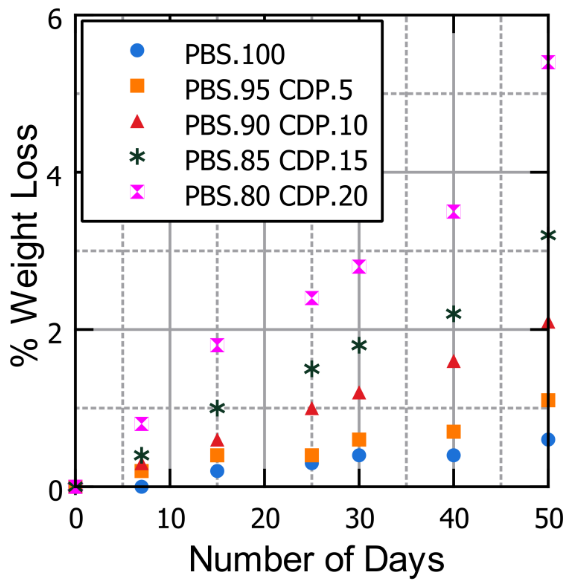
6.4 Biodegradability Study

Any object made by plastic have major problem for environment because of its long life without biodegradability properties and make it serious issue for soil health, so various researchers work on biocomposite materials made by PBS plastic material to improve the biodegradability of the composite. In present study the CDP powder was mixed with PBS to make the biocomposite materials. In present section the biodegradability investigation of the mix combinations of the biocomposite materials and the study was performed for 50 days test analysis of the objects. The results of the biodegradability test for the fabricated objects were present in table 5 and the results were show in Figure 7.

Table 5. Weight loss of PBS/CDP composite for during several days

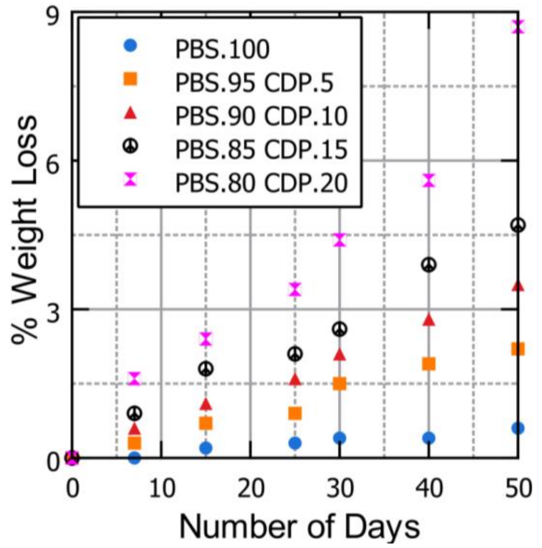
250 µm							
PBS %	**CDP %**	**0**	**7**	**15**	**25**	**30**	**40**
100	**0**	0.0	0.0	0.2	0.3	0.4	0.4
95	**5**	0.0	0.2	0.4	0.4	0.6	0.7
90	**10**	0.0	0.3	0.6	1.0	1.2	1.6
85	**15**	0.0	0.4	1.0	1.5	1.8	2.2
80	**20**	0.0	0.8	1.8	2.4	2.8	3.5
500 µm							
PBS %	**CDP %**	**0**	**7**	**15**	**25**	**30**	**40**
100	**0**	0.0	0.0	0.2	0.3	0.4	0.4
95	**5**	0.0	0.3	0.7	0.9	1.5	1.9
90	**10**	0.0	0.6	1.1	1.6	2.1	2.8
85	**15**	0.0	0.9	1.8	2.1	2.6	3.9
80	**20**	0.0	1.6	2.4	3.4	4.4	5.6

The highest weight loss due to mix of CDP powder in PBS plastic made biocomposite was equal to 9% within 50 days which was much better then neat PBS composite. It was found that those with a particle size of 500 µm had a slightly higher percentage of weight loss than those with a particle size of 250 µm. This was due to insufficient interfacial adhesion between the CDP and the PBS matrix, resulting in a material that was easily disintegrated into its component parts. This was attributed to the superior internal structure of the composite reinforced with finer fibers. The reason for this is explained in the preceding sentence[24,60].



(a)

Sasimowski et al.[60] conducted a biodegradability study on PBS/wheat-barn composites and found that pure PBS showed a weight loss of 0.06% per day, while the composite containing 50% wheat barn had a weight loss of 0.9% per day. In the current study, the weight loss per day for pure PBS was 0.012%, and for the PBS80/CDP20 composite it was 0.174%.



(b)500 µm particle size

Fig. 7: Biodegradability study for a) 250 µm CDP b) 500 µm CDP particle composite

It was found that the amount of weight loss was directly proportional to the concentration of CDP particles, with the greatest weight loss observed at a CDP content of 20%. This relationship held true for both small and large particle sizes. CDP, a natural fiber with hydrophilic properties, facilitated the absorption of water and microbes from the soil due to its hydrophobic nature. The contact between water and PBS was increased in the presence of CDP, leading to hydrolysis in the polymer and a reduction in molecular weight due to the action of fungi and bacteria in the natural soil burial process. This decrease in molecular weight resulted in the observed percentage weight loss[28,46,48,61].

6.5 Prediction and Optimization of Performance parameters of Bio Composite

The descriptive statistical table (table 6) presents an analysis of various properties of a PBS/CDP composite, consisting of 40 samples out of 60 samples. The cow dung particle size is 250 µm and 500 µm, with a standard deviation of 126.6. The percentage of PBS and cow dung powder in the samples are 90.0% and 10.0%, respectively, both with a standard deviation of 7.2%. The minimum percentage of cow dung powder is 0.0%, while the maximum is 20.0%.

The average number of days required for weight loss Is 35.0, with a standard deviation of 11.3 days and ranging from 20.0 to 50.0 days. The tensile strength has a mean value of 22.1 Mpa, a standard deviation of 3.7 Mpa, and varies between 16.9 and 27.2 Mpa. The impact energy averages at 3.1 kJ/m2, with a standard deviation of 0.7 kJ/m2 and a range from 2.1 to 4.2 kJ/m2. The melt flow index has a mean of 44.8 g/10 min, a standard deviation of 9.0 g/10 min, and values ranging from 29.4 to 55.6 g/10 min. The water absorption property shows an average value of 2.3%, a standard deviation of 1.0%, and ranges from 0.8 to 3.9 %. The density has a mean of 1.1 kg/m3, a standard deviation of 0.1 kg/m3, and values between 1.0 and 1.2 kg/m3. Lastly, the bio-degradability of the material has a mean of 2.1 %, a standard deviation of 1.8 %, and varies from 0.2 to 8.7 %. This analysis provides valuable insights into the material's characteristics and can be helpful in determining its potential applications and performance.

Table 6. Descriptive Statistical analysis of all output parameters used in ML modeling

Parameters	particle_size	percentage_PBS	percentage_cow_dung_powder	days_for_weight_loss	tensile_strength	impact_energy	bio_degradability
count	40	40.0	40.0	40.0	40.0	40.0	40.0
mean	375.0	90.0	10.0	35.0	22.1	3.1	2.1
std	126.6	7.2	7.2	11.3	3.7	0.7	1.8
min	250.0	80.0	0.0	20.0	16.9	2.1	0.2
25%	250.0	85.0	5.0	27.5	18.9	2.5	0.6
50%	375.0	90.0	10.0	35.0	21.6	2.9	1.8
75%	500.0	95.0	15.0	42.5	25.4	3.4	2.8
max	500.0	100	20.0	50.0	27.2	4.2	8.7

The table 7 presents a comprehensive comparison of the performance results of various machine learning models in predicting several properties of the PBS/CDP composite, including bio-degradability, density, impact energy, melt flow index, tensile strength, and water absorption. The XT model also demonstrated the lowest mean squared error (MSE) of 0.17, mean absolute error (MAE) of 0.37, and root mean squared error (RMSE) of 0.41, which highlights the model's precision and accuracy in predicting this property.

For density prediction, both the Decision Tree (DT) and XT models achieved perfect scores, with R2 values of 1.00, reflecting a perfect correlation between predicted and actual values. These models also exhibited the lowest possible error values, with MSE, MAE, and RMSE all equal to 0.00, emphasizing their excellent performance in predicting the material's density.

In predicting the material's impact energy, the DT, XT, and AdaBoost models all performed exceptionally well, achieving R2 scores of 1.00, which indicates a perfect match between the predicted and actual values. These models also exhibited minimal error values, confirming their strong predictive capabilities for impact energy. Regarding the melt flow index, the DT, XT, and AdaBoost models showcased superior performance, all achieving the highest R2 scores of 1.00, which suggests a perfect correlation between the predicted and observed values. These models also demonstrated the lowest error values, confirming their excellent ability to predict this property accurately. For tensile strength prediction, the DT, XT, and AdaBoost models once again demonstrated outstanding performance, all achieving R2 scores of 1.00, indicating a perfect correlation between the predicted and actual values. These models also showed minimal error values, emphasizing their strong predictive capabilities in determining the tensile strength of the material. Lastly, in predicting water absorption, the DT, XT, and AdaBoost models all achieved perfect R2 scores of 1.00, reflecting an ideal match between their predictions and the actual data. These models also exhibited the lowest possible error values, underscoring their excellent performance in predicting this property.

The Extra Trees, Decision Tree, and AdaBoost models consistently demonstrated the strongest performance in predicting the various properties of the PBS/CDP composite. These models consistently achieved high R2 scores and low error values across all categories, indicating their accuracy, precision, and reliability in predicting material properties. As such, they can be considered the top-performing models for this particular dataset and application.

Table 7. Comparative analysis of all ML models used in present study

Model	output	R2	MSE	RMS
RandomForest	bio_degradability	0.88	0.39	0.63
LinearRegression		0.87	0.43	0.65
SVR		0.76	0.83	0.91
Kneighbors		0.67	1.12	1.06
Ridge		0.87	0.45	0.67
DT		0.44	1.89	1.37
RF		0.88	0.39	0.63
XT		0.95	0.17	0.41
AdaBoost		0.47	1.78	1.33
RandomForest	density	0.99	0.00	0.01
LinearRegression		0.84	0.00	0.03
SVR		0.19	0.00	0.07
Kneighbors		0.74	0.00	0.04
Ridge		0.84	0.00	0.03
DT		1.00	0.00	0.00
RF		0.99	0.00	0.01
XT		1.00	0.00	0.00
AdaBoost		0.99	0.00	0.01
RandomForest	impact_energy	0.99	0.00	0.05
LinearRegression		0.78	0.07	0.27
SVR		0.93	0.02	0.15
Kneighbors		0.73	0.09	0.30
Ridge		0.78	0.07	0.26
DT		1.00	0.00	0.00
RF		0.99	0.00	0.05
XT		1.00	0.00	0.00
AdaBoost		1.00	0.00	0.04

7. Conclusion

This study successfully developed a machine learning-based optimization method for determining the optimal composition of biocomposites made from poly butylene-succinate (PBS) and cow dung powder (CDP) for enhanced machining performance during drilling operations. The investigation of various PBS/CDP biocomposite formulations revealed that the optimal CDP content for balancing mechanical properties and biodegradability was found to be around 10 wt%. The mechanical properties of the biocomposite improved due to the interaction between the CDP and the PBS matrix, while the highest CDP content (20 wt%) resulted in increased biodegradability.

Furthermore, the study demonstrated that using CDP microparticles instead of fibers resulted in a higher melt flow index, improved dispersion within the biocomposite matrix, and a more brittle material. Although the brittleness may pose challenges for certain applications, the overall biodegradability and mechanical properties of the PBS/CDP biocomposites make them promising candidates for eco-friendly materials in various industries.

The machine learning approach empl”yed ’n this study proved to be a valuable tool for identifying the ideal biocomposite composition, enabling researchers to streamline the material design process and reduce the need for extensive experimental trials. Future work should focus on refining the machine learning algorithms and exploring the potential of these biocomposites in other manufacturing processes or applications, as well as evaluating their long-term durability and environmental impact. This study lays the foundation for the development and optimization of sustainable, high-performance biocomposite materials that align with the growing global demand for eco-friendly alternatives to traditional materials.

The analysis of various machine learning models for predicting the properties of the PBS/CDP composite, including bio-degradability, density, impact energy, melt flow index, tensile strength, and water absorption, revealed that the Extra Trees, Decision Tree, and AdaBoost models consistently outperformed the other models. These models demonstrated high R2 scores, indicating a strong correlation between their predictions and the actual data, as well as low error values, emphasizing their accuracy and precision.

The superior performance of the Extra Trees, Decision Tree, and AdaBoost models suggests that these models are well-suited for predicting the properties of the material in question, making them valuable tools for researchers and engineers working on material development and optimization. Their reliable predictive capabilities can aid in understanding the material’s behavior, performance, and potential applications, ultimately contributing to more efficient and sustainable material design and usage.

It is essential, however, to keep in mind that the performance of machine learning models can be influenced by factors such as the quality and representativeness of the training data, as well as the selection of appropriate model hyperparameters. Therefore, it is crucial to ensure that the models are trained on diverse and representative datasets and to fine-tune the model's hyperparameters for optimal performance. Overall, the results of this analysis provide valuable insights into the capabilities of various machine learning models for predicting material properties and can serve as a basis for further research and development in the field of materials science and engineering.

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