Research Article

A Novel Study of Synthesis and Experimental Investigation on Hybrid Biocomposites for Biomedical Orthopedic Application

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In recent years the biocomposites are highly utilized in the biomedical applications, due to excellent strength as well as weight ratio. A lot of natural fibers, namely, flax, hemp, jute, kenaf, and sisal are cheaply available in colossal amount. Aim of this study, a novel approach, is executed for construction of biomedical orthopedic parts by using mixture of natural fibers. This work handled biocomposites such as flax fiber (FX), chicken feather fiber (CF), kenaf fiber (KF), and rice husk fiber (RH) effectively. From all these composites, four sets of mixed fibers with reinforcement of polylactic acid polymer used for creating orthopedic parts. The hand-lay-based methodology is undertaken for preparation of hybrid biocomposites. Parameters involved for this study are fiber types (KF + RH, RH + FX, FX + CF, and CF + KF), laminate count (2, 4, 6 and 8) infill density (30%, 60%, 90%, and 120%), and raster angle (0/60, 30/120, 50/140, and 70/160). Finding of this work is dimensional accuracy, flexural strength, and shore hardness that are analyzed by L16 orthogonal array. ANOVA statistical analysis is enhanced and enlightens the results of flexural strength and source hardness of the biocomposites. Amongst in four parameters, the fiber type parameter extremely contributes such as 40.50% in the flexural analysis. Similarly, laminate count parameter highly contributes such as 31.01% in the shore hardness analysis.

1. Introduction

In recent trends, the biomedical applications are fulfilled by the composite material especially biocomposites. The natural fibers are produced the biocomposites with reinforcement of polymer. Natural fibers possess low weight and high strength; hence, it has used in the industrial applications particularly in medical appliances. It has best suited for preparation of composites due to no environmental affects for humans. Biocomposites are prepared by blending of biofibers, namely, jute, hemp, kenaf, and sisal. Biocomposites are employed hugely in biomedical applications. Few of the biocomposites applications are tissue engineering, orthopedics, dental post, bone plate, composite pins, screws, and clips in spinal fusion. The study of chemical treatment to the natural fibers is vital role in composite preparation. Flax fiber was considered the chemical processing with 80 hours in room temperature [1]. Using of cotton cellulose and nanohydroxyapatite is excellent use in bone tissue engineering. Morphological study of the electrospun and thermal analysis is major role in the tissue engineering [2]. In bioengineering, the bone study is conducted, and the two cell lines designate the cell and proportional cell feasibility study through PVP concerned samples [3]. Blending of polylactic acid and polycaprolactone polymers into the hydroxyapatite (nHA) on the shape memory performance is conducted. The morphology study is carried out by applying of field emission scanning electron microscopy [4, 5]. A strong literature
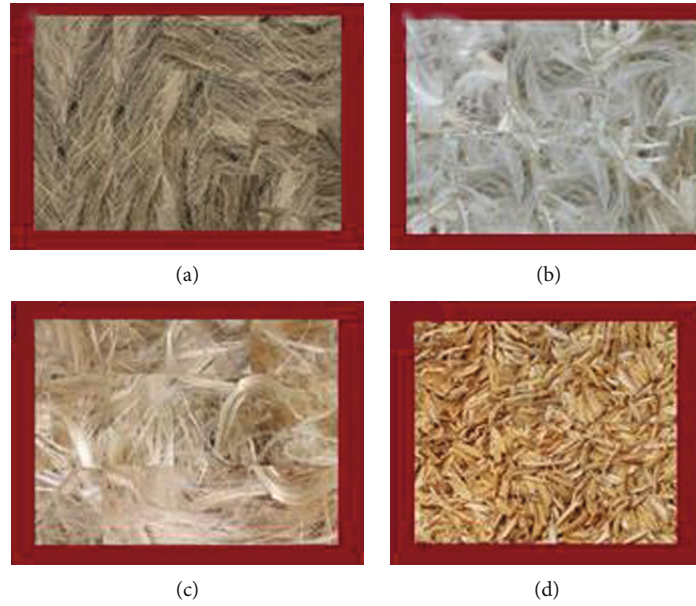
(a)

(b)

(c)

(d)

FIGURE 1: Natural fibers: (a) flax fiber, (b) chicken feather fiber, (c) kenaf fiber, and rice husk fiber.
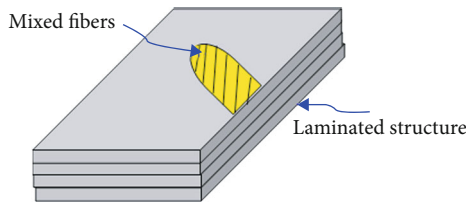

FIGURE 2: Natural fibers with PLA laminated structure.

TABLE 1: Process parameters and their values of biocomposite preparation.

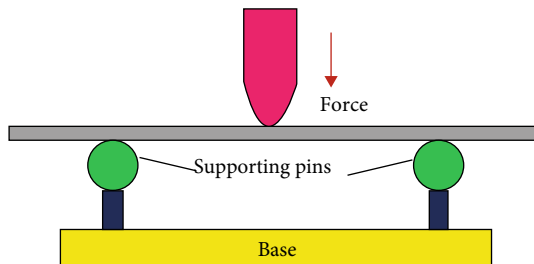| Factors	Level 1	Level 2	Level 3	Level 4
Fiber types	KF + RH	RH + FX	FX + CF	CF + KF
Laminate count	2	4	6	8
Infill density (%)	30	60	90	120
Raster angle	0/60	30/120	50/140	70/160

FIGURE 3: Flexural setup.

review is made on the natural fibers with forming of hybridization composites. The prepared composites are analyzed, parameters influences are studied, and the synthetic and natural fibers properties are briefly surveyed. Authors are

TABLE 2: Summary of flexural strength and influence of input parameters.

Exp. runs	Fiber types	Laminate count	Infill density (%)	Raster angle	Flexural strength (MPa)	S/N ratio
1	KF + RH	2	30	0/60	15.23	23.6540
2	KF + RH	4	60	30/120	18.34	25.2680
3	KF + RH	6	90	50/140	17.35	24.7860
4	KF + RH	8	120	70/160	20.47	26.2224
5	RH + FX	2	60	50/140	22.91	27.2005
6	RH + FX	4	30	70/160	21.05	26.4650
7	RH + FX	6	120	0/60	18.40	25.2964
8	RH + FX	8	90	30/120	17.39	24.8060
9	FX + CF	2	90	70/160	19.08	25.6116
10	FX + CF	4	120	50/140	20.05	26.0423
11	FX + CF	6	30	30/120	18.73	25.4508
12	FX + CF	8	60	0/60	17.34	24.7810
13	CF + KF	2	120	30/120	20.31	26.1542
14	CF + KF	4	90	0/60	23.07	27.2610
15	CF + KF	6	60	70/160	24.89	27.9205
16	CF + KF	8	30	50/140	19.57	25.8318

TABLE 3: Response table for means (flexural strength).

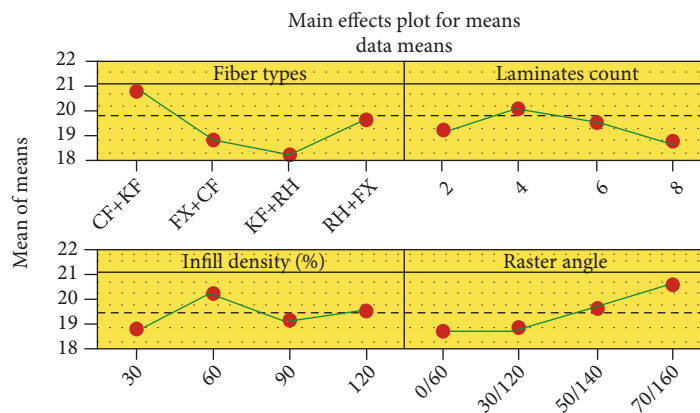| Level	Fiber types	Laminate count	Infill density (%)	Raster angle
1	19.94	19.38	18.65	18.51
2	18.80	20.63	20.87	18.69
3	17.85	19.84	19.92	19.97
4	21.96	18.69	19.81	21.37
Delta	4.11	1.93	2.22	2.86
Rank	1	4	3	2

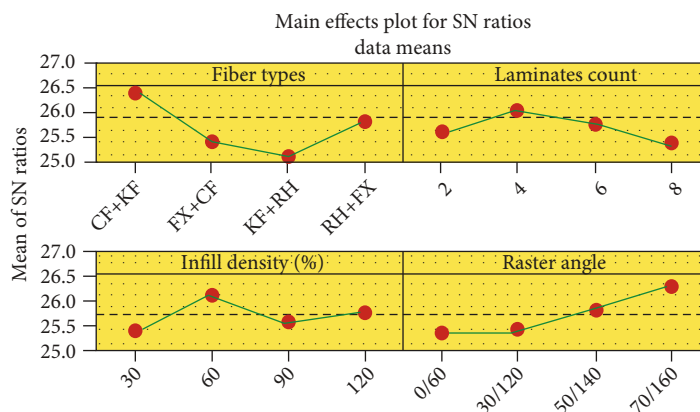FIGURE 4: Main effect plot for means (flexural strength).

FIGURE 5: Main effect plot for S/N ratio (flexural strength).

putting effort to review the resulting properties of hybrid composites, namely, mechanical, thermal, water absorption, tribological behavior, and morphological [6]. In the human health bone, problems are rectified by using of biocomposites materials, and fracture of the bone is corrected by newly prepared biocomposites. Biodegradable polyesters are highly influenced in the bone engineering products, namely, implants and surgical tubing [7]. Biocomposite materials are produced by man-made effort that fibers are replace of living tissues of the human body. Human functions are restored by using of biocomposite devices named as biosensors, pacemakers, and artificial hearts [8]. The plan of this investigation is focused on the orthopedic applications by using of natural fibers such as flax fiber, chicken feather fiber, kenaf fiber, and rice husk fiber. Considered the reinforcement of polymer such as polylactic acid with the natural fibers are enhance the flexural strength and shore hardness of the biocomposites. Taguchi statistical analysis is conducted for this experimental work to improve the strength of the biocomposites [9]. Novelty of this work is combined of different natural fibers. Different combinations of fibers are offered good flexural strength and shore hardness compared to the previous research results. Novelty implemented is reflected in the results such as pair of natural fibers that enhanced the composite strength [10].

2. Materials and Methods

The objective of this study is preparing the hybrid biocomposites for orthopedic applications with using of different natural fibers. The fibers are namely flax fiber (FX), chicken feather fiber (CF), kenaf fiber (KF), and rice husk fiber (RH). All the fibers are procured from Vruksha Composites & Services, Chennai. The PLA—polylactic acid polymers—is selected for this work to reinforce into the natural fibers [11]. PLA is highly enhanced by the flexural strength and hardness of the prepared biocomposites. This composite is vastly used in the biomedical applications such as orthopedic parts [12]. Required quantity of polylactic acid polymers is procured from Natur Tec India Private Limited. The composites are prepared by hand-lay methodology with effective use of PLA polymer. Steel mould and hand roller tools are utilized to prepare the composites by the way of hand layup methodology. Using of P ratham 5.0 3D Printer (Make: Pratham, India), it can be operated by Repetier, Slicer software package. Pratham 5.0 delivers the molten material with the nozzle dimensions of 0.4 mm.
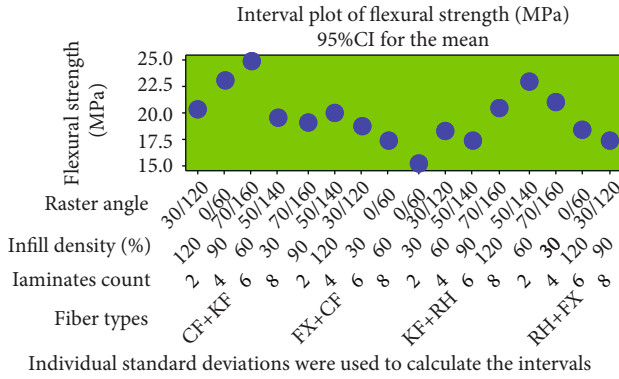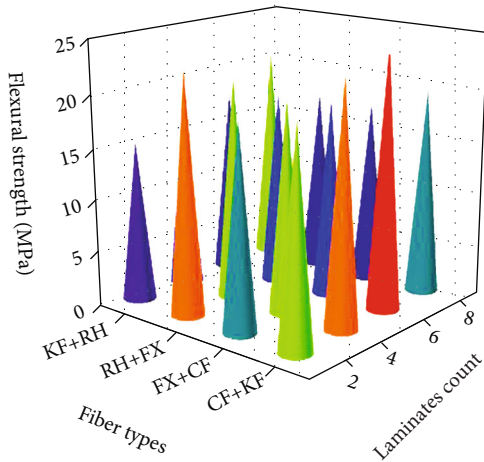
Figure 6: Interval plot of flexural strength.

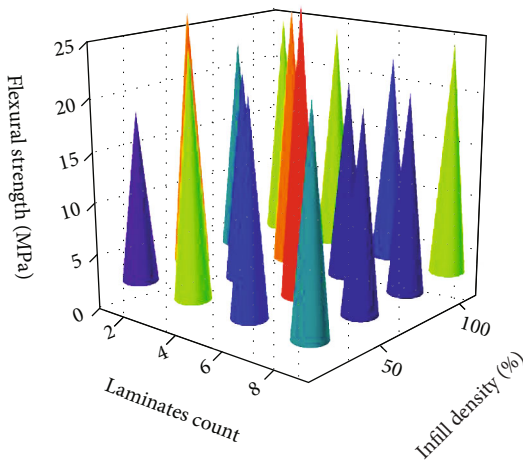Figure 7: Flexural strength: 3D plot of fiber types and laminate count.

Figure 8: Flexural strength: 3D plot of laminate count and infill density.
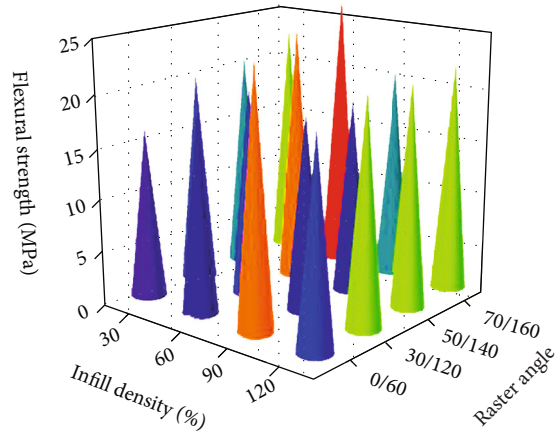

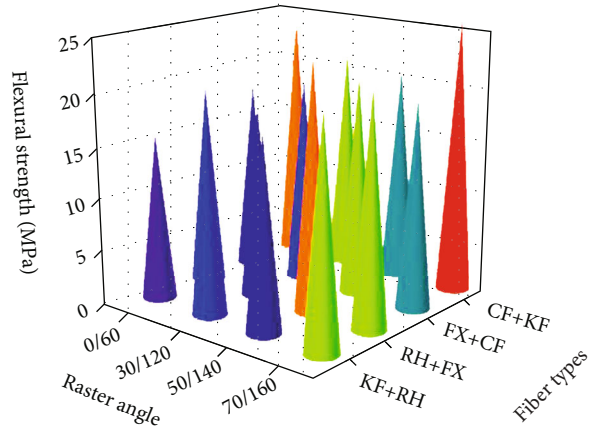Figure 9: Flexural strength: 3D plot of infill density and raster angle.

Figure 10: Flexural strength: 3D plot of raster angle and fiber types.

Table 4: Response table for signal to noise ratios (flexural strength).

Level	Fiber types	Laminate count	Infill density (%)	Raster angle
1	25.54	25.66	25.35	25.25
2	25.47	26.26	26.29	25.42
3	24.98	25.86	25.62	25.97
4	26.79	25.41	25.93	26.55
Delta	1.81	0.85	0.94	1.31
Rank	1	4	3	2

3. Experimental Procedure

There are multiple stages that are involved to clean the fibers, and it can be discussed in detail manner. Initially, the cleansing process is carried out to clean the fibers thoroughly with the help of sodium hypochlorite (NaOCl).

Taken of 30 liters of distilled water with mixing of 300 ml of 35% solution, namely, sodium hypochlorite, is in a vessel [13, 14]. Stirring action is maintained at a frequency level of 15 Hz with a time period of 45 min. This cleaning process carried out three times for achieve healthy fibers [15]. Further continue of washing process of the fibers is carried out by using hydrogen peroxide (H_2O_2). Using of this process, taken of 150 ml of 20% solution of H_2O_2 is mixed in 30 liters of distilled water; the homogeneous mixing is obtained by maintaining of 10 Hz and 45 min. Finally, completions of chemical processing all the fibers are dried well for 20 hrs

TABLE 5: Analysis of variance of flexural strength.

Source	DF	Seq SS	Contribution (%)	Adj SS	Adj MS	F value	P value
Regression	12	77.440	83.51	77.440	6.453	1.27	0.478
Fiber types	3	37.558	40.50	37.558	12.519	2.46	0.240
Laminate count	3	7.921	8.54	7.921	2.640	0.52	0.699
Infill density (%)	3	10.821	11.67	10.821	3.607	0.71	0.608
Raster angle	3	21.140	22.80	21.140	7.047	1.38	0.398
Error	3	15.293	16.49	15.293	5.098		
Total	15	92.733	100				

TABLE 6: Summary of shore hardness and influence of input parameters.

Exp. runs	Fiber types	Laminate count	Infill density (%)	Raster angle	Shore hardness (HD)	S/N ratio
1	KF + RH	2	30	0/60	72.13	37.1623
2	KF + RH	4	60	30/120	75.00	37.5012
3	KF + RH	6	90	50/140	74.00	37.6042
4	KF + RH	8	120	70/160	70.85	37.0068
5	RH + FX	2	60	50/140	73.00	37.2665
6	RH + FX	4	30	70/160	72.38	37.1924
7	RH + FX	6	120	0/60	75.37	37.5440
8	RH + FX	8	90	30/120	69.89	36.8883
9	FX + CF	2	90	70/160	78.25	37.8697
10	FX + CF	4	120	50/140	77.34	37.7681
11	FX + CF	6	30	30/120	72.01	37.1479
12	FX + CF	8	60	0/60	73.64	37.3423
13	CF + KF	2	120	30/120	77.29	37.7625
14	CF + KF	4	90	0/60	76.65	37.6902
15	CF + KF	6	60	70/160	74.89	37.9205
16	CF + KF	8	30	50/140	72.01	37.2318

with 600°C with the aid of hot air oven [16, 17]. In this experimental work, the automatic fiber placing mechanism is accomplished in the fiber count as well as uniform placing of the fibers [18]. The different natural fibers are chosen for this experimental work that is illustrated in Figure 1.

The composite specimen is prepared as per the ASTM D790 standard for conducting of flexural test to find the strength of the specimens. Using of solid work software package in the 3D model of the specimens is to be created as shown in Figure 2. Created 3D model is exported into the FDM machine with stereolithography layout, and this format is used for easy accessible in printing [19]. Applying of hand-lay technique, the fibers are inserted into the specimen with PLA polymer reinforcements through manually. Insertion of layer of fiber, laminate count, infill density, and raster angle is predetermined with the help of vast literature study [20–22]. The process parameters and the values of the biocomposites are presented in Table 1.

The Taguchi L16 OA is selected for estimate of the parameters that influence as well as the outcome of the work by Taguchi statistical tool.

3.1. Dimensional Accurateness. Dimensional accurateness of the composite structures is analyses by using of a digital Ver-

TABLE 7: Response table for means (shore hardness).

Level	Fiber types	Laminate count	Infill density (%)	Raster angle
1	49.60	75.17	59.02	74.45
2	75.31	75.34	61.20	73.55
3	60.49	60.07	62.20	60.48
4	72.66	58.49	75.21	61.59
Delta	25.71	26.28	16.19	25.97
Rank	3	1	4	2

nier calliper under the least count of 0.01 mm: make: aerospace. Dimensional accurateness is based on the thickness of the composite structure in this work; the insertion of fibers has the higher influence in the strength of the composites [23–25]. Dimensional accurateness is estimated by the difference between dimensions of the specimen in design stage and the production stage.

3.2. Shore-D Hardness. Shore hardness is measured in the prepared biocomposites by shore hardness tester (make: Linear Instruments Chennai), avoiding the human and environmental errors while in hardness testing by taken of readings
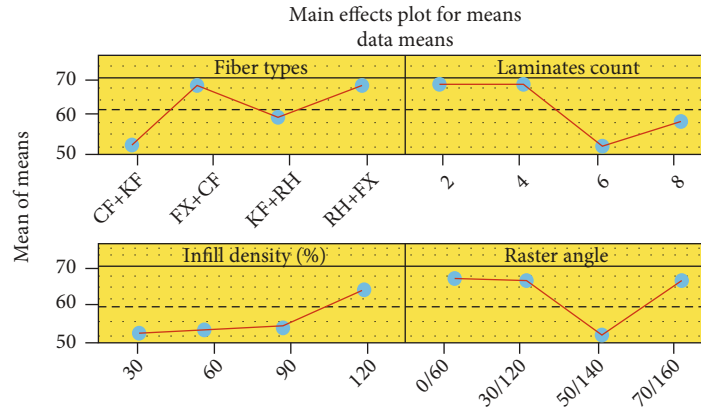
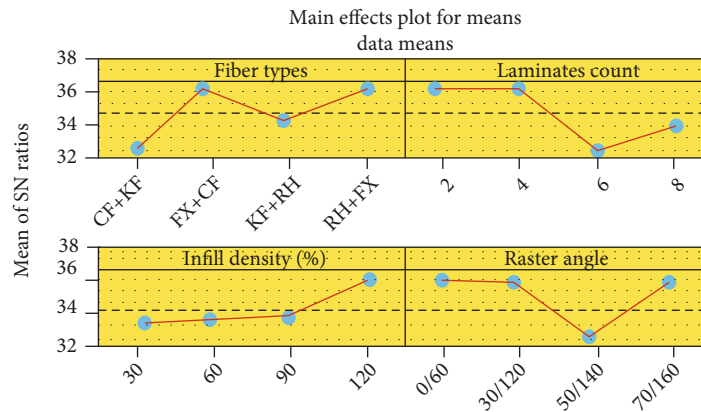FIGURE 11: Main effect plot for means (shore hardness).

FIGURE 12: Main effect plot for S/N ratio (shore hardness).

in three times for each specimen finally considered the average values [26].

3.3. Flexural Testing. Using of universal testing machine the flexural test is conducted, the UTM Make: Universal grip company, Salem. This machine having a 5 kN load cell generally the testing speed for polymer composite material is set by 3 mm/min based on the ASTM standard [27]. The bottom portion of the UTM machine is utilized for conducting of flexural test, and the specimen is placed horizontally in the fixtures [28–30]. Three point flexural tests are implemented for this investigation as shown in Figure 3.

The load is acting on the center portion of the specimen with suggested span-to-depth ratio that is 18 : 1. The flexural readings are displayed digitally with the aid of computer control accessories [31–33].

4. Results and Discussion

4.1. Flexural Strength. Table 2 presents the summary of flexural strength and S/N ratio of the investigation. Maximum flexural strength was obtained as 24.89 MPa by influencing of combination of chicken feather fiber and kenaf fiber, laminate count of 6, infill density of 60%, and raster angle of 70/160.

Tables 3 and 4 present the response tables for means and S/N ratio of the flexural strength [34]. Based on the rank order, the types of fiber are highly influenced and followed by raster angle, infill density, and laminate count. The optimal parameters were obtained as mixture of chicken feather fiber and kenaf fiber, 6 counts of laminates, 60% of infill density, and 70/120 of raster angle [35].

Figures 4 and 5 present the main effect plots for both means and S/N ratio of flexural strength. Based on the types of fibers, the mixture of chicken feather fiber and kenaf fiber offered excellent flexural strength compared to other mixture of fibers. Mixture of kenaf fiber and rice husk provided minimum flexural strength [36].

Taken of laminate count the 4 number of laminates offered good flexural strength, further increasing of laminate count the strength has to be gradually decreased [37]. Infill density 60% provided the maximum flexural strength, continually increasing of infill density, and the flexural strength is decreased in little amount. Raster angle is one of the important factor for deciding the flexural strength; here, maximum flexural strength offered by influence of higher angle 70/160.

Figure 6 shows the interval plot of flexural strength and all parameter effects in a single plot. This plot shows that the maximum of flexural strength was found around
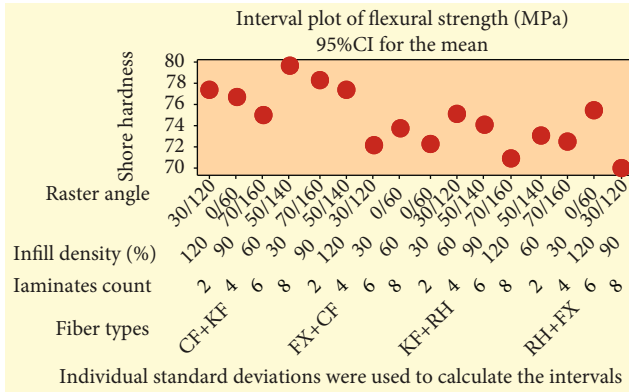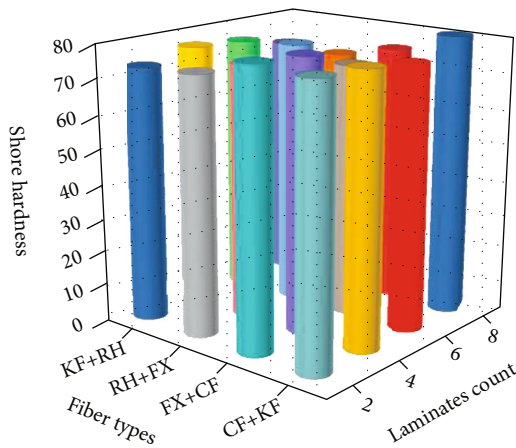
FIGURE 13: Interval plot of shore hardness.

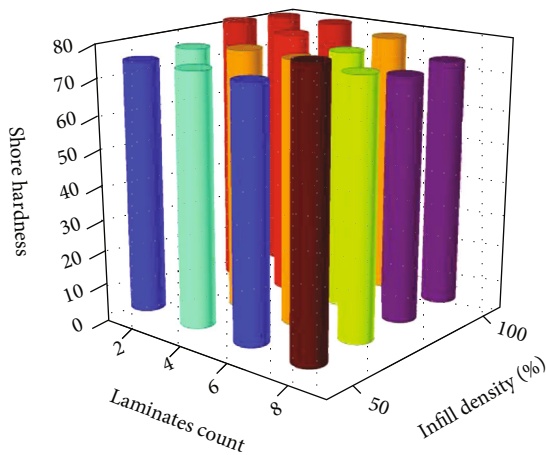FIGURE 14: Shore hardness: 3D plot of fiber types and laminate count.

FIGURE 15: Shore hardness: 3D plot of laminate count and infill density.

25 MPa of flexural strength. Parameter effects were concluded as mixture of chicken feather fiber and kenaf fiber, 6 counts of laminates, 60% of infill density, and 70/120 of raster angle.
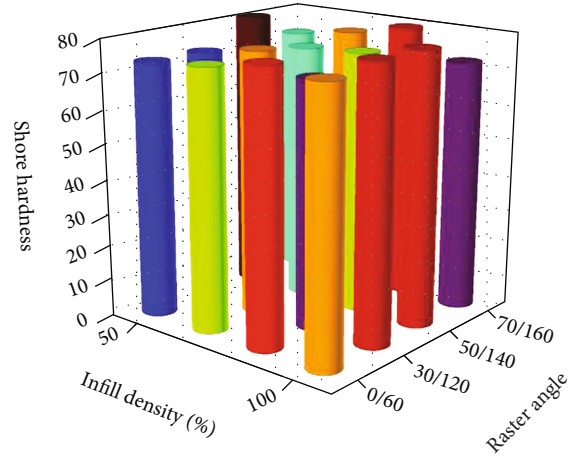

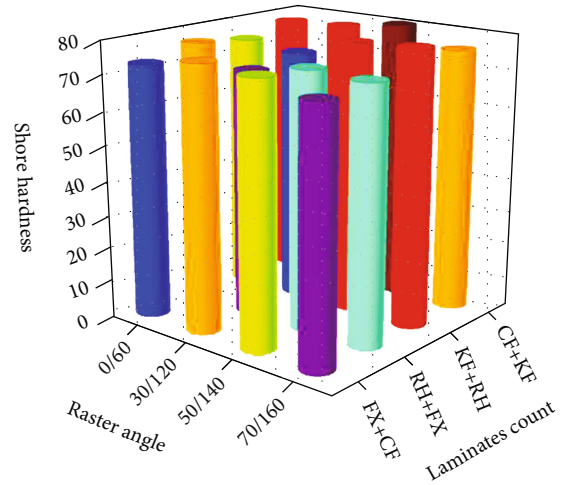FIGURE 16: Shore hardness: 3D plot of infill density and raster angle.

FIGURE 17: Shore hardness: 3D plot of raster angle and fiber types.

TABLE 8: Response table for signal to noise ratios (shore hardness).

Level	Fiber types	Laminate count	Infill density (%)	Raster angle
1	32.30	37.52	34.33	37.43
2	37.53	37.54	35.01	37.32
3	34.82	32.55	35.01	32.12
4	37.22	34.27	37.52	35.00
Delta	5.23	4.98	3.19	5.32
Rank	2	3	4	1

Figures 7–10 illustrate the 3D plot for the correlation between two parameters; Figure 7 presents the maximum flexural strength by chicken feather fiber and kenaf fiber relations to 6 counts of laminates [38]. Figure 8 illustrates that the 6 counts of laminates and 60% of infill density registered as excellent flexural strength. Figure 9 presents the 60% of infill density, and 70/120 of raster angle recorded more flexural strength. Figure 10 shows that the 70/120 of

TABLE 9: Analysis of variance of shore hardness.

Source	DF	Seq SS	Contribution (%)	Adj SS	Adj MS	F value	P value
Regression	12	6125.7	93.90	6125.7	510.5	3.85	0.147
Fiber types	3	1686.0	25.85	1686.0	562.0	4.24	0.133
Laminate count	3	2022.7	31.01	2022.7	674.2	5.09	0.107
Infill density (%)	3	633.1	9.71	633.1	211.0	1.59	0.356
Raster angle	3	1783.9	27.35	1783.9	594.0	4.49	0.125
Error	3	397.6	6.10	397.6	132.5		
Total	15	6523.3	100				

raster angle and chicken feather fiber and kenaf fiber combination registered as higher flexural strength [39].

Table 5 presented the analysis of variance of flexural strength effectively, among in all four parameters, the fiber type parameter was highly influenced such as 40.50%, followed by raster angle (22.850%), infill density (11.67%), and laminate count (8.54%).

4.2. Shore Hardness. Table 6 presents the summary of shore hardness and S/N ratio of the investigations. Highest shore hardness was found as 78.25 HD by influencing of blend of flax fiber and chicken feather fiber, minimum laminate count such as 2, 90% of infill density, and maximum raster angle (70/160).

Tables 7 and 8 present the response tables for means and S/N ratio of the shore hardness of the composite materials. Among in four parameters, the laminate count was the chief factor to effects in the shore hardness analysis. There parameter effects were analyzed through the rank order; in second rank, the raster angle was contributed'; in third, rank fiber types was influenced; finally, the infill density was involved as fourth rank of the analysis. In shore hardness analysis, the optimum parameters were found to be as mixture of rice husk fiber and flax fiber, laminate count was 4, infill density was 120%. and raster angle was 0/45.

Figures 11 and 12 illustrate the main effect plot for both means and S/N ratio of shore hardness. These plots clearly demonstrated the all four factors and the influences in the response values. From the analysis, the types of fibers, the mixture of flax fiber, and chicken feather fiber registered exceptional shore hardness contrast to remaining mixture of fibers. In the consideration of laminate count parameter, minimum count such as 2 offered better shore hardness. Increasing of laminate count decreases the shore hardness values. Parameter of infill density influences highly, and increasing of infill density raises the shore hardness values. Maximum hardness was obtained by using of 12.5 of infill density. Minimum raster angle parameter such as 0/60 recorded maximum shore hardness, and increasing of raster angle decreases the shore hardness values.

Figure 13 presents the interval plot of shore hardness with effects of all parameters in a single plot. From this plot, the highest shore hardness was noted clearly that the value of maximum shore hardness values reached 80 HD. All parameters were extremely influenced, and the effects were concluded as blending of chicken feather fiber and kenaf

fiber, 8 counts of laminates, 30% of infill density, and 50/140 provided extreme value of hardness.

Figures 14–17 demonstrate the 3D plot with the relationship between two parameters, and Figure 14 illustrates that the maximum shore hardness by involvement of chicken feather fiber and kenaf fiber links to 8 counts of laminates. Figure 15 presents the correlations of 8 counts of laminates and 30% of infill density found as excellent shore hardness Figure 16 represents the 30% of infill density, and 50/140 of raster angle offered more shore hardness. Figure 17 shows that the 50/140 of raster angle and chicken feather fiber and kenaf fiber amalgamation recorded superior shore hardness.

Table 9 presents the analysis of variance of shore hardness efficiently; amongst in all four parameters, the laminate count parameter was extremely influenced such as 31.01%, pursued by raster angle (27.35%), fiber types (25.85%), and infill density (9.71%).

5. Conclusion

Biomedical applications such as orthopedic parts were produced by using of biocomposites, namely, flax fiber, chicken feather fiber, kenaf fiber, and rice husk fiber. PLA, polylactic acid polymer, was used as reinforced into the selected natural fibers to improve the flexural strength and shore hardness of the biocomposites. Taguchi optimization was involved to maximize the outcome of this investigation and estimated the optimal parameters. Results of this investigation were summarized as follows:

(i) In the flexural analysis, the maximum flexural strength was recorded as 24.89 MPa. The optimal parameters were attained as combination of chicken feather fiber and kenaf fiber, 6 counts of laminates, 60% of infill density, and 70/120 of raster angle. Mixture of chicken feather fiber and kenaf fiber offered remarkable flexural strength compared to other mixture of fibers. Among in four parameters, the fiber type parameter was extraordinarily influenced such as 40.50%, followed by raster angle (22.850%), infill density (11.67%), and laminate count (8.54%)

(ii) From shore hardness analysis, the highest shore hardness was found as 78.25 HD. The optimum parameters were registered as mixture of rice husk fiber and flax fiber, laminate counts were 4, infill

density was 120%, and raster angle was 0/45. Mixture of flax fiber and chicken feather fiber provided excellent shore hardness compare to remaining mixture of fibers. Amid in four parameters, the laminate count parameter was exceptionally influenced such as 31.01%, followed by raster angle (27.35%), fiber types (25.85%), and infill density (9.71%)

(iii) In the flexural analysis, 60% of infill density and 70/120 of raster angle recorded more flexural strength. Similarly, 70/120 of raster angle and chicken feather fiber and kenaf fiber combination registered as higher flexural strength

(iv) In shore hardness analysis, 8 counts of laminates and 30% of infill density recorded as excellent shore hardness. Similarly, 30% of infill density and 50/140 of raster angle offered more shore hardness. The 50/140 of raster angle and chicken feather fiber and kenaf fiber combination recorded better shore hardness

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, these are 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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