Hindawi
Journal of Nanomaterials
Volume 2022, Article ID 9704980, 12 pages
https://doi.org/10.1155/2022/9704980

Research Article

Flame Resistance Characteristics of Woven Jute Fiber Reinforced Fly Ash Filled Polymer Composite

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Received 3 November 2021; Revised 23 December 2021; Accepted 27 January 2022; Published 12 February 2022

Academic Editor: Pandiyarasan Veluswamy

Due to their unique characteristics, natural fiber reinforced polymer composites have recently been increasingly utilised to replace traditional materials. Fire retardant resins can increase flammability, and they have a deleterious influence on the mechanical properties of the material (Fan et al., 2020). As a result, this experiment examined the flammability of woven jute fiber reinforced with fly ash. The specimens were created by hand layup using a L9 orthogonal array and varying ratios of jute fiber, fly ash, and time for chemical fiber treatment. Vertical and horizontal flammability tests are conducted in accordance with ASTM D635 and ASTM D3801, respectively. According to the test results, the inclusion of fly ash significantly reduces flammability. In this work, 5 wt% inclusion of the jute fiber, 15 wt% addition of the fly ash, and with 10 hours, NaOH treatment produces a composite with minimum burning rates of 10.2 mm/min in horizontal UL-94 tests. To determine the link between input and output characteristics, various regression models from machine learning are used. Multilayer perception produced a stronger association in both horizontal and vertical testing, according to the models.

1. Introduction

Numerous plants and animals are naturally exploited to obtain fibers. Apart from this, numerous synthetic fibers are manufactured and reinforced. The shelf life and degree of biodegradability of fibers are determined by their physical and chemical structure. Synthetic fibers have superior mechanical properties over natural fibers since they are manufactured specifically for their intended use. Due of their unique characteristics and abundant availability, natural fibers are frequently used as reinforcement in polymer composites. Salem et al. examined the fundamental features of jute fiber reinforced composites and discovered that by increasing the interfacial bonding between the fiber and matrix, and the thermomechanical properties can be enhanced [1]. Ashraf et al. conducted a critical analysis and addressed recent advances in jute-based composites. Additionally, they illustrated the various issues associated with the excessive use of synthetic composites [2]. Saravanan et al. and Dinesh et al. discussed the challenges associated with developing composites reinforced with jute fiber using a variety of manufacturing techniques and reported on their mechanical properties. They discussed the mechanism through which the material degrades using scanning electron microscopy [3, 4]. Roya et al. investigated the fire resistance of jute cloth treated with flame retardants and discovered that the treated specimens developed char and contained minimal volatiles [5]. Zaman et al. examined the challenges associated with developing natural fiber-reinforced composites with superior mechanical characteristics and chemical and flame resistance. They used a variety of treatments on natural jute fibers to strengthen the interfaces with resins [6]. Wang et al. conducted a characterisation study on silane-treated jute fabric and evaluated its thermal and surface properties, concluding that the treated fibers demonstrated increased stability in hot conditions due to the structures, as well as improved tensile characteristics [7]. Khalili et al. developed biodegradable composites by using flax fibers with hydroxyapatite nanoparticles. They discovered that the addition of flax fiber enhances the flexural and tensile modulus, whereas the presence of nano-HA reduces the strength and increases the water intake [8]. Sonnier et al. investigated the differences in fire retardancy between natural, glass, and carbon fiber reinforced composites and discovered that, when compared to natural fibers, carbon and glass fibers exhibit greater resistance to flame [9]. Shah et al. evaluated the flame resistance capabilities of numerous natural fiber composites and concluded that the inclusion of appropriate additives increases the natural fibers' flame resistance. He demonstrated that silicon-based additives perform better [10]. Oktem et al. enhanced the fire resistance and mechanical capabilities of hybrid jute/flax composite buildings while maintaining their attractive appearance. They enhanced these properties by a variety of chemical treatments [11]. Rashid et al. investigated the flame resistance of green composites and discovered that the synergistic technique significantly reduces the peak temperature rate while silane treatment enhances the decomposition temperature [12]. Mathubala and Nandhini synthesised jute fiber composites and investigated their heat and fire resistance properties, concluding that fiber adherence and bonding to the matrix improve the composites' fire resistance properties [13]. Latif et al. concentrated on the production of nanocomposites utilising vinyl ester as the matrix and jute cloth as the reinforcement. Additionally, they concentrated on organo-modified montmorillonite (OMMT), which has a high aspect ratio and a low surface charge density [14]. Shahinur et al. investigated the thermal properties of composites reinforced with jute fiber and discovered that fiber that had been chemically treated absorbed less heat than untreated samples [15]. Salimov et al. investigated the flammability and fire resistance of certain natural fiber and textiles in order to safeguard them from fire. Additionally, they provided the findings of their investigation [16]. Ribeiro et al. investigated the flame resistance of jute fiber reinforced epoxy composites intended for tile applications and discovered that the incorporation of jute fiber had no effect on the fire resistance [17].

Sakthi Balan et al. incorporated waste plastics and eggshells into composites along with jute and bahunia racemose fiber reinforcement and evaluated the composites' moisture absorption. They concluded that the addition of particulates and fillers reduces the composites' water absorption more than fiber do. Fibers promote moisture absorption because they are hydrophilic [18, 19]. Sakthi Balan et al and Navaneethakrishnan et al. improved the composite's mechanical properties to make it more resistant to environmental influences. They examined critical parameters such as tensile strength, hardness, and resistance to moisture absorption and optimised the data to determine which factor had the most influence on mechanical properties [20, 21]. Navaneethakrishnan et al. created an epoxy-based composite reinforced with MWCNTs/g-C3N4 and investigated the composite's water absorption and wear properties [22]. The properties that can be altered in the polymer composites make them versatile for applications in various fields, such as constructions, microelectronics, and biomedical fields. Devastations due to building fire stress the importance of flame-retardant polymer composites, since they are directly related to human life conservation and safety [23]. The flammability of a composite formed by reinforcing woven jute fiber with waste fly ash is investigated in this work. The data are optimised in order to determine the most significant element affecting flammability. The low-flammability specimen is recommended for usage in roofing materials as well as vehicle and airplane structures.

2. Materials and Methods

A composite is composed of a matrix as a base and a reinforcement to enhance the strength and some physical and mechanical properties. The physical and other composite characteristics can also be improved by choosing proper chemical treatment. On the whole, the strength of the polymer composite can be improved by proper chemical treatment of the fibers and by producing defect-free composites. Defects are mostly produced during the manufacturing of the composites, and proper measures have to be taken to minimize or avoid the common defects. In this work, natural fiber jute is chosen for reinforcement, a filler of fly ash is used, and its flammability studies are carried out as per the standards. Normally, fibers are used in many forms such as short fibers, long fibers, and woven fabric. When using the short and long fibers, orientation of the fibers and fiber density plays a major role. During the usage of natural fibers, the fibers have to be treated chemically to improve the bonding between the matrix and the fibers. In this work, the woven jute fabric is used which is chemically treated before usage. NaOH treatment is well suited for jute fibers.

Fly ash is used as filler material which is obtained from the thermal power plant which burns lignite-type coal. Generally, fillers are used to improve the surface and hardness properties of the composite. In this composite, the main purpose of using the filler is to reduce the pore formation during the production of the composite and to suppress the flame propagation during the flammability test. Normally, jute fiber is flammable, but if it is reinforced into a polymer matrix along with nonflammable filler powders, the flammability property of the material changes. Three factors are chosen as important and varied during the manufacturing of the composite as per Taguchi's experimental design. Percentage of fiber addition, percentage of filler addition, and the chemical treatment are chosen as the input factors, and the composites are manufactured. After curing, the

Table 1: Orthogonal array experimental design with burning rate UL-94 results.

Percentage of jute fiber	Percentage of fly ash	NaOH chemical treatment time in hours	Burning rate (mm/min) Horizontal UL-94 test	Burning rate (mm/min) Vertical UL-94 test	Cotton ignition	Classification
5	5	0	13.4	14.5	No	v0
5	10	5	10.8	12.3	No	v0
5	15	10	10.2	11.2	No	v0
10	5	5	17.1	19.4	No	v1
10	10	10	13.9	15.3	No	v1
10	15	0	11.8	13.1	No	v0
15	5	10	22.5	24.3	No	v1
15	10	0	19.9	21.2	No	v1
15	15	5	18.7	20.5	No	v1

composites are tested for their flammability by following the standard procedure as per ASTM standards. The jute fibers are chemically treated with NaOH with fixed concentrations. One set of fibers is used as untreated, and another set is treated for 5 hours and another set for 10 hours. After chemical treatment, the fibers are flushed with ordinary water and dried in an oven. Then, the filler powder fly ash is collected from the thermal power plant is sieved to remove the foreign particles and particles of varying sizes. The fly ash filler must be of the same size and as it is collected from the cyclonic separator and water scrubber, and the fly ash is also dried in the oven and then used. As the fiber and fillers are added in weight percentages, both are weighed before adding to the composite.

The composites are manufactured by compaction process using mild steel mold. The traditional hand layup process is used for making the composite. The epoxy is mixed in an equal ratio with the hardener, and the filler powder is also mixed along with resin and layered on the surface of the mold. Then, the woven jute fabric fiber which is chemically treated is stacked over the resin-filler mixture and then again a layer of resin and filler is layered. The process is repeated until the required thickness is obtained and then the composite is closed with a top cover and tightened using bolts and nuts. The whole setup is kept in the compression molding machine and given pressure so that the excess resin can be removed, and this compression removes the air trapped inside the composite stacking. Then, the setup is left undisturbed for 12 hours for curing, and then the composite is removed from the mold. The mold is then cleaned and used for stacking the next set of composite with different input factors.

3. Flammability Studies

Flammability tests on polymer composite materials are conducted according to the ASTM D635 protocol for horizontal UL–94 testing and ASTM D3801 process for vertical UL–94 testing. A specimen size of 1251333 mm is required to complete a flammability test. The test is carried out by fixing the specimen in horizontal and vertical directions with the help of a stand. Below the specimen, the base must be filled with a layer of cotton to check the dripping from the specimen. A Bunsen burner is used to fire the specimen. The fire is introduced at the open end of the specimen for 10 seconds and then removed and allowed to propagate along the length of the specimen. A stopwatch has to be used for calculating the time taken for the specimen to burn from 25 mm to 100 mm. This process is repeated for all nine specimens, and the burning rate of the material is calculated using the following equation.

$$\text{Rate of Burning (mm/min)} = 60 \times \frac{\text{Length of the sample burnt (mm)}}{\text{Sample burning time (Seconds)}}. \quad (1)$$

Based on the time taken for the specimen to burn, the specimens are classified under v0, v1, and v2 classes. If the burning time is less than 10 seconds and without igniting the cotton, then, the specimen is classified under v0 category which has high flame resistance. If the specimen burns for less than 30 seconds and could not ignite the cotton at the bottom, then, it comes under v1 category. If the specimen burns less than 50 seconds and if the cotton underneath the specimen got ignited, then, it falls under v2 category which has less flame retardant. Some specimen burns completely and that falls under NC (no classification). The specimen without any dripping and has less burning time can be identified as a specimen with high flammable resistance.

4. Results and Discussion

Flammability tests were executed as per the standard procedure, and the cotton ignition was also checked for the dripping nature of the composite materials. The tested composites are categorized under three categories as v0, v1, and v2 based on the burning time of the composites. In Table 1, the parameters that are varied for the manufacturing of the composites and their different levels are listed along with the flammability test results. The results of the test were fed into MINITAB software for regression analysis and ANOVA table formation [24, 25]. Various plots are plotted during optimization to study the behavioral pattern of the results.

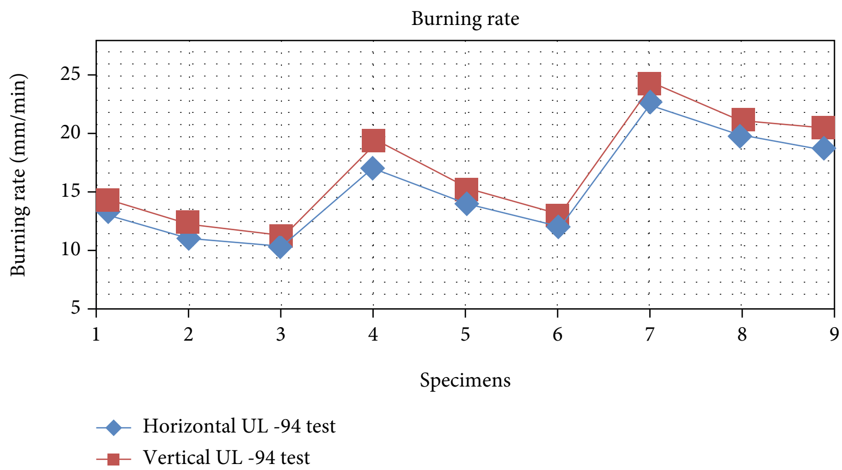

FIGURE 1: Burning rate—horizontal UL 94 vs. vertical UL 94 test results.

TABLE 2: Difference in values between horizontal and vertical UL-94 tests.

Specimen number	Burning rate (mm/min) Horizontal UL-94 test	Vertical UL-94 test	Difference in values
1	13.4	14.5	1.1
2	10.8	12.3	1.5
3	10.2	11.2	1
4	17.1	19.4	2.3
5	13.9	15.3	1.4
6	11.8	13.1	1.3
7	22.5	24.3	1.8
8	19.9	21.2	1.3
9	18.7	20.5	1.8

In Figure 1, the burning rate data for the nine specimens are presented alongside the results of the horizontal and vertical flame tests. The plot reveals that the test results are fairly similar and that the difference between them is very small. Table 2 indicates the difference in values between the horizontal and vertical UL-94 tests.

4.1. ANOVA for Horizontal Test. In Table 3, variance results for the flat test were mentioned, and the Fischer value suggests that the addition of jute fibers affects the firing ability of the material, and fly ash addition also suppresses the propagation of the fire. From the main effect plotting, as shown in Figure 2, the influence of the input parameters can be proved once again.

$$\begin{aligned}\text{Regression Equation for Horizontal UL} - 94\text{ test}\\ = 10.32 + 0.8900\text{ Composition of Jute fibers}\\ - 0.4100\text{ Composition of Fly ash}\\ + 0.0500\text{ NaOH treatment.}\end{aligned} \tag{2}$$

In Figures 3 and 4, the interaction between the input factors and the relation between the two most influencing factors were mentioned, respectively, through interaction and contour plots. From the contour plot observation, for minimum flammability, the inclusion of jute fiber must be 5 wt% and fly ash inclusion must be 15 wt%. From Figure 5, the contribution of factors can be understood. The equation for regression analysis of both the horizontal and vertical flammability tests was designated in equations (2) and (3).

4.2. ANOVA for Vertical Test. In Table 4, ANOVA results were tabulated, and the summary of the model is also tabulated.

$$\begin{aligned}\text{Regression equation for Vertical UL} - 94\text{ test}\\ = 11.67 + 0.933\text{ Composition of Jute fibers}\\ - 0.447\text{ Composition of Fly ash}\\ + 0.067\text{ NaOH treatment.}\end{aligned} \tag{3}$$

To know the significance of the model, the regression square value is verified. *R*-squared measures the strength of the relation between a model and the dependent variable on a convenient scale. After fitting a linear regression model, it determined how well the model fits the data. Based on the experimental results, the *R* squared value changes; in this work, we got the *R*-square value is 95.50% for vertical test and 95.10% for horizontal test, which indicates the significance of the model. Fischer's value from Table 4 indicates the influence of each input factor on the results. From the *F* value, the composition of the fibers was found to be the most influential factor and the addition of the fly ash to the composite also has some influence on the flammability property of the composite. The main effect plot shown in Figure 6 is plotted for signal-to-noise ratio with a smaller is better principle. The plot indicates the jute fiber addition influences the results more as that plot shows more deviation. As per the smaller is a better concept, the addition of the jute fiber must be minimum, the addition of the fly ash must be maximum, and the chemical treatment has a very negligible amount of contribution in deciding the flammability property.

The interaction plot in Figure 7 shows the interlinkage between the input factors. In Figure 8, the contour plot

Table 3: ANOVA results for horizontal test.

Source	DF	Adj SS	Adj MS	F value	P value
Regression	3	144.405	48.135	32.37	0.001
Composition of jute fibers	1	118.815	118.815	79.9	0
Composition of fly ash	1	25.215	25.215	16.96	0.009
NaOH treatment	1	0.375	0.375	0.25	0.637
Error	5	7.435	1.487		
Total	8	151.84			
S	R-sq	R-sq(adj)		R-sq(pred)	
1.21943	95.10%	92.17%		82.83%	

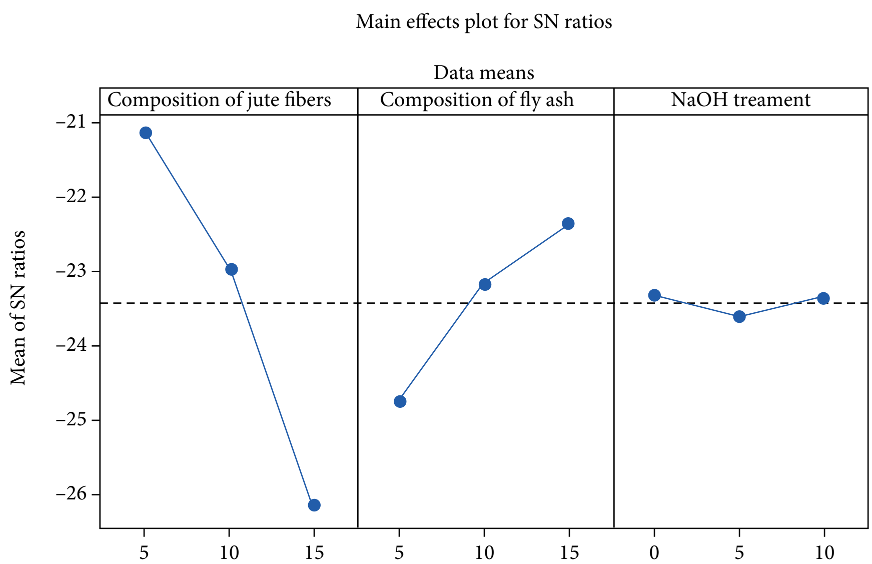

Figure 2: Main effect plotting for horizontal flame test.

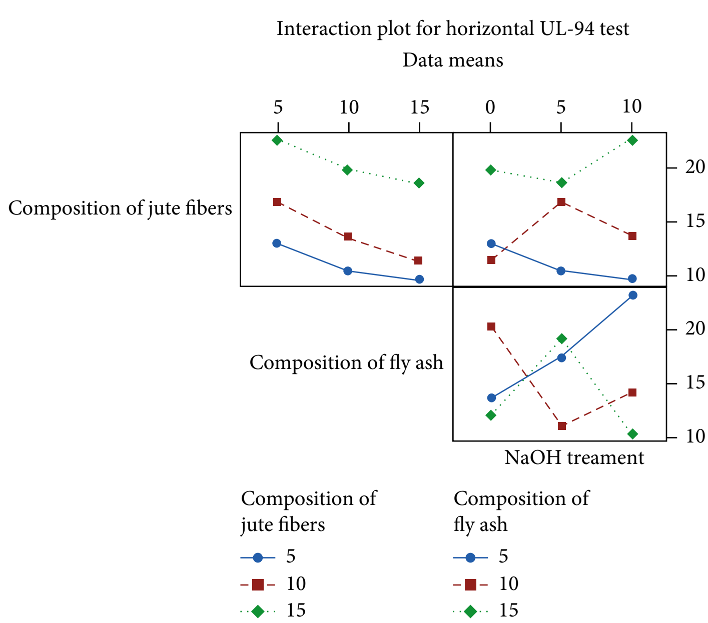

Figure 3: Interaction plotting for horizontal flame test.

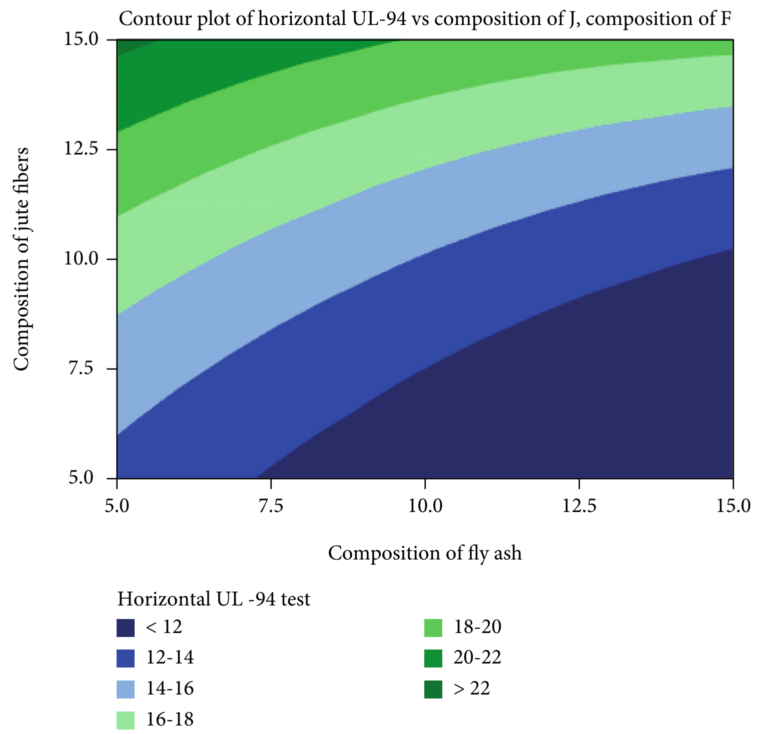

Figure 4: Contour plotting for horizontal flame test.

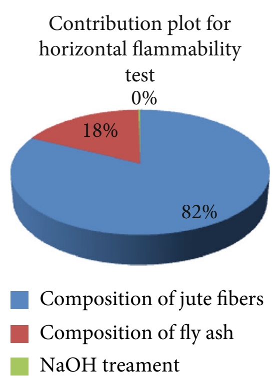

Figure 5: Contribution chart for horizontal flame test.

indicates the best optimum level to obtain minimum burning rates. From the contour plot, for getting lower burning rates, the inclusion of fiber should be minimized, and the addition of the fly ash must be increased. As the fiber used in this composite is a natural fiber, the tendency to catch fire is more and so if the percentage addition of the fiber is more, the burning rates are also found to be increased which is not advisable. The fly ash addition seems to lower the burning rates as it is already obtained from burning the coal. The ash will diminish the fire and tends to form char, which will stop the propagation of the fire throughout the material. As the fly ash was added in powder form, it reduces the defects formed during the production of the composite. The major defect formed in a polymer composite during the production is the formation of blowholes and surface cracking. The fly ash fills the holes formed in the core and surface of the composites and also improves the surface properties and reduces the microcracks formed during curing. The NaOH chemical treatment has no contribution in determining the burning properties of the composite. Maybe it can influence the strength and other properties of the composite. The addition of the jute fiber increases the burning rate by 81%, and the fly ash addition minimizes it by 19% which can be understood by the contribution plot shown in Figure 9.

4.3. Regression from Machine Learning. Regression analysis is performed to forecast the value of yield values from the set of independent variables. In addition, it is used to find the effect of input data on the dependent variable. Recently, many researchers are using machine learning models that are capable of analyzing complex data with more accurate results. Navaneethakrishnan et al. [22] used linear regression, MLP, and SVR in addition to ANOVA to find the best regression model to predict the output parameters. Hence, in this work also, various regression models from machine learning are applied. To apply these algorithms, WEKA open source software is used. Tables 3 and 4 show the regression models for both horizontal and vertical tests. Figure 10 shows the difference between various output parameters.

In Table 5, output data of the machine learning analysis were tabulated, the difference between the actual value and linear regression, MLP, and SVR was plotted, and the error bars indicate the levels of variation between the regression values and actual burning rate values of the horizontal test. Table 6 shows the error values between the actual value and the three regression analysis values. Error value 1 shows the difference between actual value and linear regression values, error value 2 shows the difference between actual

Table 4: ANOVA results for vertical test.

Source	Degrees of freedom	Adjacent sum of squares	Adjacent mean sum of squares	Fischer value	*P* value
Regression	3	161.26	53.753	35.36	0.001
Composition of jute fibers	1	130.667	130.667	85.96	0
Composition of fly ash	1	29.927	29.927	19.69	0.007
NaOH treatment	1	0.667	0.667	0.44	0.537
Error	5	7.6	1.52		
Total	8	168.86			
S	R-sq	R-sq(adj)		R-sq(pred)	
1.23288	95.50%	92.80%		86.31%	

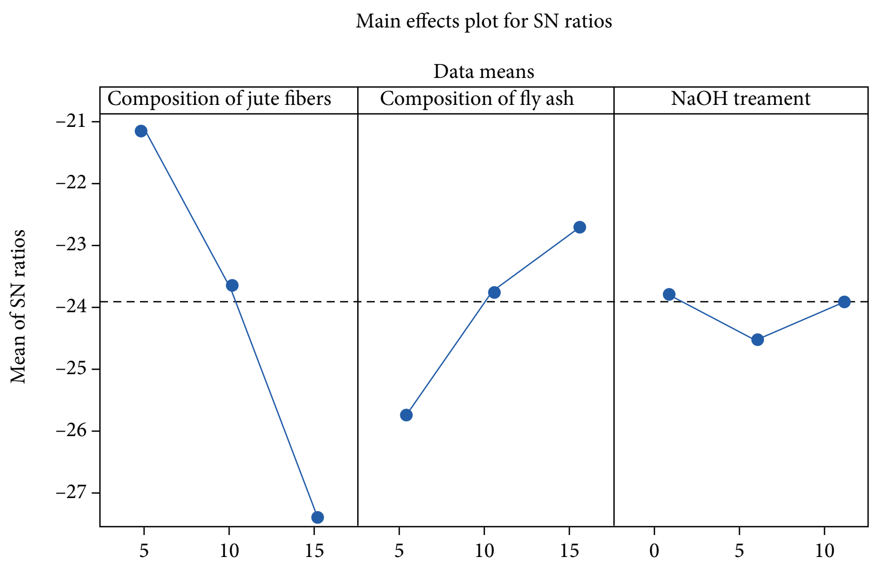

Figure 6: Main effect plot for SN ratios.

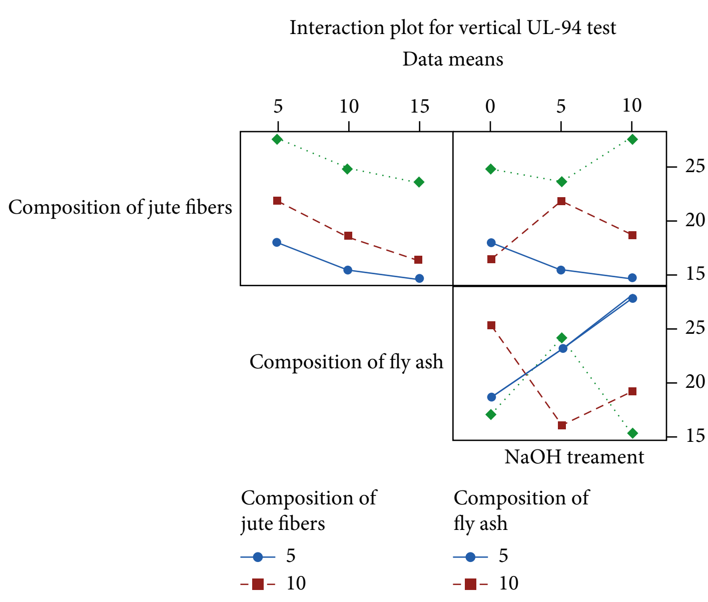

Figure 7: Interaction plot for vertical UL-94 test results.

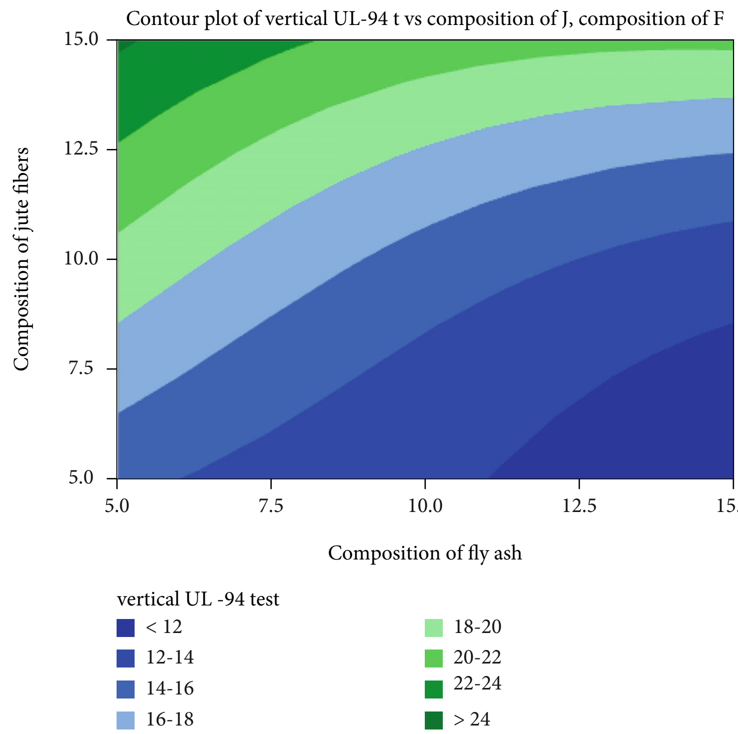

Figure 8: Contour plot for vertical UL-94 test results.

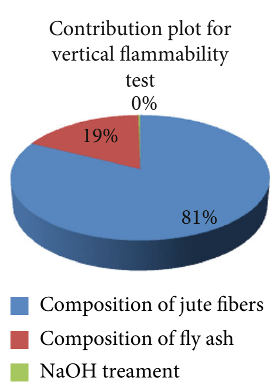

Figure 9: Contribution chart for vertical UL-94 test results.

values and multilayer perception values, and error value 3 indicates the difference between actual and support vector regression values for horizontal tests. The regression equations of linear, MLP, and SVR are mentioned in equations (4), (5), and (6), respectively. Table 7 shows the machine learning analysis results for vertical test.

LR:

$$\text{Burning rate} : 0.2249 + 0.7236 \text{ x Jute fiber} - 0.333\text{xFly ash}. \tag{4}$$

MLP:

$$\begin{aligned}\text{Burning rate} : &-0.86728\ (\text{Threshold}) + 2.853\text{x}(\text{Jute fiber}) \\ &- 0.4437\text{x}(\text{fly ash}) + 0.1025\text{x}(\text{NaOH}).\end{aligned} \tag{5}$$

SVR:

$$\begin{aligned}\text{Burning rate} : &\ 0.1932 + 0.7309\ (\text{jute fiber}) - 0.271\text{ x}(\text{fly ash}) \\ &+ 0.0759\text{ x}(\text{NaOH}).\end{aligned} \tag{6}$$

Table 8 shows the error values between the actual value and the three regression analysis values. Error value 1 shows the difference between actual value and linear regression values, error value 2 shows the difference between actual values and multilayer perception values, and error value 3 indicates the difference between actual and support vector regression values for vertical tests. From Figure 11, the contrast between the actual burning rates of the specimen and the machine learning outputs were studied. Specimens 5, 6, and 9 show some deviation, and other values are nearer to the machine learning results. Based on the below-mentioned equations (7), (8), and (9), the regression analysis was carried out using machine learning.

LR:

$$\text{Burning rate} : 0.2468 + 0.7125 \text{ x Jute fiber} - 0.341 \text{ x Fly ash}. \tag{7}$$

MLP:

$$\begin{aligned}\text{Burning rate} : &-0.514\ (\text{Threshold}) + 3.477\text{ x }(\text{Jute fiber}) \\ &- 0.496\text{ x }(\text{fly ash}) - 0.2931\text{ x }(\text{NaOH}).\end{aligned} \tag{8}$$

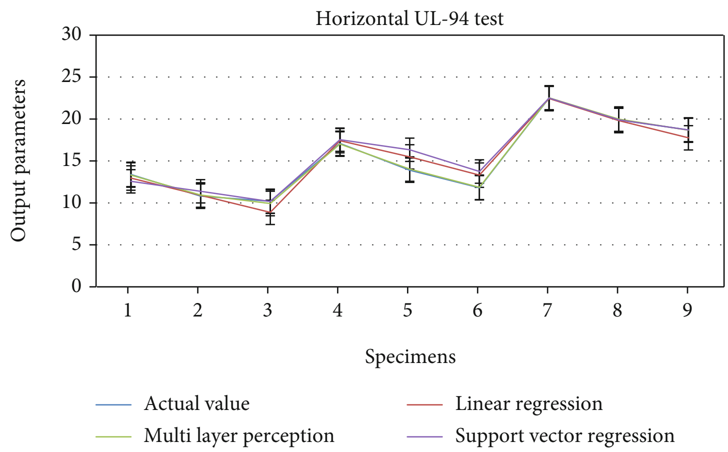

Figure 10: Difference between various output parameters.

Table 5: Machine learning analysis results for horizontal test.

Sl. no.	Input parameters			Output parameters (burning rate)			
	Jute fiber %	Fly ash %	NaOH treatment time in hours	Actual value	Linear regression	Multilayer perception	Support vector regression
1	5	5	0	13.4	12.9675	13.3242	12.5739
2	5	10	5	10.8	10.9134	10.938	11.3808
3	5	15	10	10.2	8.8716	9.9294	10.1754
4	10	5	5	17.1	17.4201	17.0142	17.5431
5	10	10	10	13.9	15.489	14.0376	16.3377
6	10	15	0	11.8	13.3119	11.8605	13.7424
7	15	5	10	22.5	22.4372	22.5246	22.5
8	15	10	0	19.9	19.8186	19.9908	19.9047
9	15	15	5	18.7	17.7645	18.6747	18.6993
	Correlation coefficient				0.9739	0.9995	0.9713
	Root mean square error				0.0757	0.011	0.0895

Table 6: Error values between actual and various regression values for horizontal test.

Sl. no.	Output parameters (burning rate)						
	Actual value	Linear regression	Error value 1	Multilayer perception	Error value 2	Support vector regression	Error value 3
1	13.4	12.9675	0.4325	13.3242	0.0758	12.5739	0.8261
2	10.8	10.9134	-0.1134	10.938	-0.138	11.3808	-0.5808
3	10.2	8.8716	1.3284	9.9294	0.2706	10.1754	0.0246
4	17.1	17.4201	-0.3201	17.0142	0.0858	17.5431	-0.4431
5	13.9	15.489	-1.589	14.0376	-0.1376	16.3377	-2.4377
6	11.8	13.3119	-1.5119	11.8605	-0.0605	13.7424	-1.9424
7	22.5	22.4373	0.06273	22.5246	-0.0246	22.5	0
8	19.9	19.8186	0.0814	19.9908	-0.0908	19.9047	-0.0047
9	18.7	17.7645	0.9355	18.6747	0.0253	18.6993	0.0007

SVR:

$$\text{Burning rate}: 0.2516 + 0.6748\,(\text{jute fiber}) - 0.3267\,\text{x}(\text{fly ash}) + 0.0733\,\text{x}\,(\text{NaOH}). \tag{9}$$

From Tables 3 and 4, it is evident that all the regression models have a correlation coefficient of more than 0.97, and its mean square value is less than 0.07. This shows a strong association among parameters of both input and output. From the equations, it is also understood that jute fiber has a positive correlation, and fly ash has a negative correlation. It shows that by addition of fly ash reduces the burning rate and the effect of NaOH is very less. These results were confirmed with the ANOVA test.

Table 7: Machine learning analysis results for vertical test.

Sl. no.	Input parameters: Jute fiber %	Fly ash %	NaOH treatment time in hours	Output parameters (burning rate): Actual value	Linear regression	Multilayer perception	Support vector regression
1	5	5	0	14.5	14.4357	14.4357	14.5012
2	5	10	5	12.3	12.1956	12.7196	12.8375
3	5	15	10	11.2	9.9686	11.1214	11.1738
4	10	5	5	19.4	19.0993	19.3744	19.4006
5	10	10	10	15.3	16.8723	15.523	17.7369
6	10	15	0	13.1	14.6322	13.3353	14.6322
7	15	5	10	24.3	23.7629	24.3262	24.3
8	15	10	0	21.2	21.5359	21.4442	21.1953
9	15	15	5	20.5	19.2958	20.501	19.5316
		Correlation coefficient			0.9752	0.9993	0.9767
		Root mean square error			0.0732	0.0152	0.0785

Table 8: Error values between actual and various regression values for vertical test.

Sl. no.	Output parameters (burning rate): Actual value	Linear regression	Error value 1	Multilayer perception	Error value 2	Support vector regression	Error value 3
1	14.5	14.4357	0.0643	14.4357	0.0643	14.5012	-0.0012
2	12.3	12.1956	0.1044	12.7196	-0.4196	12.8375	-0.5375
3	11.2	9.9686	1.2314	11.1214	0.0786	11.1738	0.0262
4	19.4	19.0993	0.3007	19.3744	0.0256	19.4006	-0.0006
5	15.3	16.8723	-1.5723	15.523	-0.223	17.7369	-2.4369
6	13.1	14.6322	-1.5322	13.3353	-0.2353	14.6322	-1.5322
7	24.3	23.7629	0.5371	24.3262	-0.0262	24.3	0
8	21.2	21.5359	-0.3359	21.4442	-0.2442	21.1953	0.0047
9	20.5	19.2958	1.2042	20.501	-0.001	19.5316	0.9684

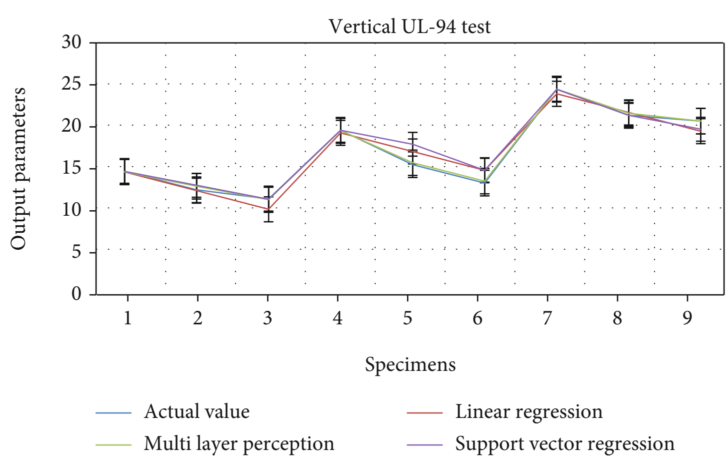

Figure 11: Difference between various output parameters for vertical test.

5. Conclusion

Flammability tests are done especially for the composites manufactured with natural fiber reinforcement, as by nature natural fibers have high burning properties when compared to manmade fibers. The test carried out for flammability of polymers and plastic materials used in electronic devices is expressed as UL-94. The test results were rated as V0, V1, and V2 based on the extinguishing of the flames after removing the burner.

Thus, the natural fiber-reinforced composite with jute fiber reinforcement and fly ash filler addition was manufactured and tested for its flammability. From the results obtained from the testing and optimization, the addition of the jute fiber influences more and increases the flammability property of the composite, and the inclusion of the fly ash reduces the burning rates of the composites. The results were verified by referring to various plots and graphs. The optimum levels obtained from the plot are with 5 wt% inclusion of the jute fiber, 15 wt% addition of the fly ash, and with 10 hours chemical treatment; minimum burning rates can be obtained. In horizontal UL-94 tests, 10.2 mm/min burning rate, and in vertical UL-94 tests, 11.2 mm/min burning rate was obtained. Validation tests were also carried out with these levels, and the results obtained show minimum deviation from the predicted values which are acceptable. To analyze the process parameters' effects on flammability, ANOVA, LR, MLP, and SVR were used.

The regression models also indicate that jute fiber induces the burning rate due to positive correlation and whereas fly ash reduces the burning rate due to negative correlation. The effect of NaOH is very less on the burning rate. In the future, fly ash could be added as a reinforcement agent to reduce the flammability for other natural fibers and greatly reduce the flammability affecting electronic parts. As it is self-extinguishable, it can be used in places where the material needs to be requiring more resistance to flames.

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.

Disclosure

It was performed as a part of the Employment Hawassa University, Ethiopia.

Conflicts of Interest

The authors of this article declare that we have no conflict of interests.

Acknowledgments

The authors appreciate the technical assistance to complete this experimental work from the Department of Mechanical Engineering, K. Ramakrishnan College of Engineering, Tiruchirappalli. The authors are thankful for the technical assistance to complete this experimental work.

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