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Fabrication and Optimization of Wear Behaviour of Citrus Limetta Peel Particulate Composite using Hybrid Taguchi-GRA-PCA

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Abstract: As the world of composite materials evolves, it will be necessary to use inexpensive and readily available natural materials as reinforcement. In present research work, epoxy composite reinforced with citrus limetta peels is fabricated by hand Layup setting using epoxy, hardener and powdered citrus limetta peel. Under dry conditions, the material was subjected to wear analysis on "Pin on Disc" wear testing equipment. Using Minitab 18 software a Taguchi "L_9 Orthogonal Array", a plan of experiment was prepared to determine the wear behaviour in terms of wear and frictional force. The two output response elements, namely wear and friction force, have been chosen, and Taguchi analysis has been carried out on each individual output parameter. "Smaller-the-Better" option has been chosen for Taguchi Analysis. Using Taguchi analysis, signal to noise ratios have been developed for wear and friction force. The response factors with smaller values would result in superior composite structures. The wear property of composite was found to be affected by modifying applied load, sliding speed, and sliding time. The best combination of process settings resulted in the least amount of dry sliding wear possible. The ideal composite structure for wear and friction force is achieved when the load is 10 N, the test time is 4 minutes, and the sliding speed of RPM of 400.

Keywords: Citrus limetta peels composite, Wear analysis, Taguchi-GRA-PCA.

1. Introduction

Citrus fruits can yield a variety of byproducts, including beverage bases, molasses, peel seasonings, purees, dried pulp, citrus alcohol, bland syrup, citric acid, and seed oil[1,2)]. Moreover, citrus wastes are rich in minerals that can be used as food supplements or as components in medicines[3,4)]. Mosambi (Citrus limetta), the citrus species from the rutaceae family has high pectin content and has exceptional nutritional and medicinal qualities[5)] and it is mostly used in the juice processing business[4)]. But large portion of this fruit is the peel, pulp, and seed which accounts for ~60% of fruit weight and it generates a large portion of solid waste every year[6,7)].

"Mosambi peel has a high crude fibre content (17.6%), as well as a high water and oil-holding capacity (2.26 ml/g and 6.82 ml/g, respectively)"[3,5,6)]. Antibacterial, antioxidant, anti-inflammatory, and anticancer properties have been found in citrus limetta peels[8–10)]. Citrus limetta peels are rich in phenolic compounds and have the capacity to scavenge free radicals due to their hydroxy content[11,12)]. Despite these valuable qualities, mosambi byproducts are often discarded or used for animal feed due to a lack of understanding of their potential economic uses[1,13)]. Besides, mosambi waste has no significant commercial value[10,14)]. If proper research is done, the mosambi fruit waste can be utilized for making valuable by-products. One such solution is to utilize these natural fibers (fruit waste) to fabricate composites[11,15–17)].

Natural fibers composites are becoming a viable alternative to synthetic composites[18–20)]. Natural fibres are currently being used more frequently in the composites sector because of their low cost, low density, high toughness, biodegradable, and beneficial features. Due to the negative consequences of synthetic fibres during production and disposal of finished items, natural fibres are preferred over them in the engineering sectors [21,22)]. Natural composites outperform manufactured composites in terms of environmental impact[15,23)]. They result in less reliance on nonrenewable resources, lower greenhouse gas emissions and increased energy restoration[12,24)]. These increased environmental achievements are a key factor in improving "Natural Fiber Composite" practice in the future. Natural fibres such as Bagasse, Pineapple, Ramie, Coir, Sisal, Bamboo, Banana, and others are abundant in India, and the country has focused on the development of "Natural Fiber Composite" to create value-added jobs[4,25)]. The study of polymer composites using natural fibers is a relevant research area as it offers promising mechanical properties[12,26–28)]. Furthermore, composites made from natural fibers are environmentally friendly and easily recyclable, making them suitable for recovery and reuse[29,30)].

Composites have become an increasingly important aspect of present day's materials because of their numerous advantages such as light weight, corrosion resistance etc.[31–34)]. Based on the reinforcing arrangement in the matrix, composite materials are categorized into particle composites, flake composites, and fibre composites[35–37)]. The wear behavior of epoxy composites is influenced by factors such as the type, orientation, and volume fraction of reinforcement materials (such as fibers or nanoparticles), sliding conditions (including counterface material, load, speed, and temperature), the properties of the epoxy matrix (hardness, toughness, coefficient of friction), and the processing techniques used[38,39)]. These composites can exhibit variations in wear mechanisms, including adhesive, abrasive, or fatigue wear. Testing methods such as pin-on-disk tests and microscopic analysis can assess wear rates, mechanisms, and overall performance. Optimizing wear resistance requires balancing other properties while considering mechanical strength, stiffness, and cost factors[20,23)].

In the current study mosambi peels (citrus-limetta) have been used to fabricate a composite plate. Mosambi peels (citrus-limetta) are acidic and have a pH range of 2.9 - 4.0. Citrus-limetta peel, the fruit's outer layer, is primarily made up of proteins, cellulose, basic oils, and some basic carbohydrates[8)]. In this study, particles are used as reinforcement in composites, and characterization data for particulate reinforced composites is analyzed. Citrus limetta was obtained and deformed into particles for this purpose. Hand layup technique is used to create composite from citrus limetta and polyester.

2. Materials and Methods

2.1 Fabrication of Composite Particle

Ripened mosambi fruit peels shown in Figure 1, were initially washed thoroughly and then chopped into small pieces. These pieces were then kept for drying for a week. Post drying mosambi peels were crushed in the form of powder as shown in Figure 1. This powder was then utilized to fabricate the composite.

Fig. 1: Citrus Limetta Peel and the Powder

2.2 Fabrication of composite

Casting was used to make the citrus limetta peel powder reinforced composite[40,41)]. Novolac resins epoxy has been used for their excellent chemical resistance and high-temperature stability. During the fabrication of the composite plate, hardener and accelerator have been utilized to start the curing process. The curing process was carried out at room temperature for 24 hours. A blend was created by combining 50% citrus limetta peel powder and 50% epoxy resin by volume. The epoxy resin and hardener were combined in a weight ratio of 10:1. The mixture was stirred to minimize the air bubble or void formation. The prepared mixture was poured on the cleaned surface maintaining width, breadth and thickness of the composite having cross sectional area of 1 feet[2)]. The mixture was allowed to cure at room temperature for 24 hours.

2.3 Wear characterization

The reinforced composite samples were evaluated on the disc tribometer with a DUCOM (TR-20LE) pin. EN-31 steel rotating plate with a hardness of 62 HRC is used in the setup. The rotary plate has a diameter of 120 mm and a thickness of 10 mm. During the testing of the samples, a microprocessor controls the pin on the disc tester, and wear and friction force are continuously recorded. The microprocessor is linked to a computer system, which displays wear and frictional force graphs over time. The samples being tested are 25mm x 6mm x 6mm in size and will be forced against the plate in rest condition by tightening the screws. Loads must be applied to samples using a load lever with a load sensor, and tests must be performed by spinning the disc. Samples were to be tested for dry sliding wear at room temperature. The LVDT (Linear Variable Differential Transformer) configuration continuously provided wear data in the form of displacement of the being tested sample in mm with a precision of one micrometer. Wear in micrometers and frictional force in Newton (N) will both be displayed on the screen at the same time.

2.4 Taguchi Design

It has been demonstrated by numerous researchers that the Taguchi strategy is the best method for optimization of the single objective [9,28,42)]. Taguchi and grey relational analysis (GRA) have been used to analyze the data. In the first step of the analysis, S/N ratio values for both performance factors were calculated. For enhanced wear behavior, lower levels of wear and frictional force were required. With the use of the MINITAB 18 software system, the S/N ratio was calculated. Known and unknown elements were combined in GRA to generate optimal behavior response values[32]. The key quality elements are frictional force and wear. These high-quality components are characterized by the principle that smaller size is better. To improve the friction and wear properties of the composite, the Taguchi-GRA-PCA method was used with three factors each having three levels, as depicted in Table 1.

Table 1. Process Parameters – Input factors and levels using Taguchi design

S. N.	Process Factor	3 Level of Process Factor		
		1	2	3
1.	Force/Load (N)	-10-	-20-	-30-
2.	Sliding Time (Minutes)	-3-	-4-	-5-
3.	Sliding Speed (RPM)	-300-	-400-	-500-

L9 Orthogonal Array obtained through Taguchi Design

S. N.	Normal Load (N)	Time (Minutes)	RPM
1.	-10-	3	300
2.	-10-	4	400
3.	-10-	5	500
4.	-20-	3	300
5.	-20-	4	400
6.	-20-	5	500
7.	-30-	3	300
8.	-30-	4	400
9.	-30-	5	500

3. Results and Discussion

The majority of mosambi fruits are used to make juice, resulting in a considerable amount of peel that is usually discarded. Peel has a variety of beneficial components, including fiber. The effective use of the peel form such agriculture produces can increase the value of these products, benefiting all the producers, companies and the customers.

3.1 Fabrication of Composite

The composite particles were successfully procured from mosambi peel. The amount of composite particle (Powder) formed from 1 kg of peel is approximately 300gm. Figure 2 shows the citrus limetta peel powder reinforced composite fabricated using vacuum assisted Hand Lay-Up Process.

Fig. 3: Fabricated composite

3.2 Wear Analysis

Figure 3 shows the “Pin on Disk” machine setup used to calculate the wear and friction force of the fabricated composite.

Fig. 3: Pin on Disc machine setup for wear measurement

The different wear and friction responses obtained for all the samples are tabulated in Table 2.

Maximum wear was 19 and with a friction value of 4.7 at a load of 30 N, a sliding time of 4 minutes, and a sliding speed of 400 RPM. In contrast, at a load of 10 N, 4 minutes of sliding time, and 400 RPM of sliding speed produced minimum wear and minimum friction of 6.8 and 2.7, respectively. Response of wear and friction with respect to different input parameters are shown in Table 2.

Table 2. Response Table (Wear and Friction) for three input factors (Load, sliding time, and sliding speed)

	Input			Response	
S. No.	Load (N)	Sliding Time (Minutes)	Sliding Speed (RPM)	Wear	Friction
1	10	3	300	7.6	3.1
2	10	4	400	6.8	2.7

3	10	5	500	10.0	4.1
4	20	3	300	9.3	3.2
5	20	4	400	9.0	3.9
6	20	5	500	16.0	4.6
7	30	3	300	18.0	7.7
8	30	4	400	19.0	4.7
9	30	5	500	14.0	6.0

3.3 Taguchi and Grey Relation Analysis

To optimize the wear behavior parameters i.e. frictional force and wear of the mosambi peel reinforced particle composite, Taguchi and GRA, multi-step optimization tools, has been employed.

The two output response elements, namely wear and friction force, have been chosen, and Taguchi analysis has been carried out on each individual output parameter. "Smaller-the-Better" option has been chosen for Taguchi Analysis. Using Taguchi analysis, S/N ratios (signal to noise ratios) shown in Table 3 have been developed for wear and friction force. The response factors with smaller values would result in superior composite structures. Figure 4 shows "Main effects plot for Mean S/N ratios" for wear and friction force.

Table 3. Response Table for S/N Ratios for Wear and Frictional Force

Wear vs. Load, Time, and RPM			
LEVEL	**Load (N)**	**Time (Minutes)**	**RPM**
1	-18.09	-20.70	-22.42
2	-20.85	-20.44	-19.65
3	-24.53	-22.33	-21.40
RANK	1	3	2
Friction Force vs. Load , Time and RPM			
Level	**Load (N)**	**Time (Minutes)**	**RPM**
1	-10.24	-12.55	-12.17
2	-11.73	-11.30	-11.43
3	-15.58	-13.69	-13.94
Rank	1	3	2

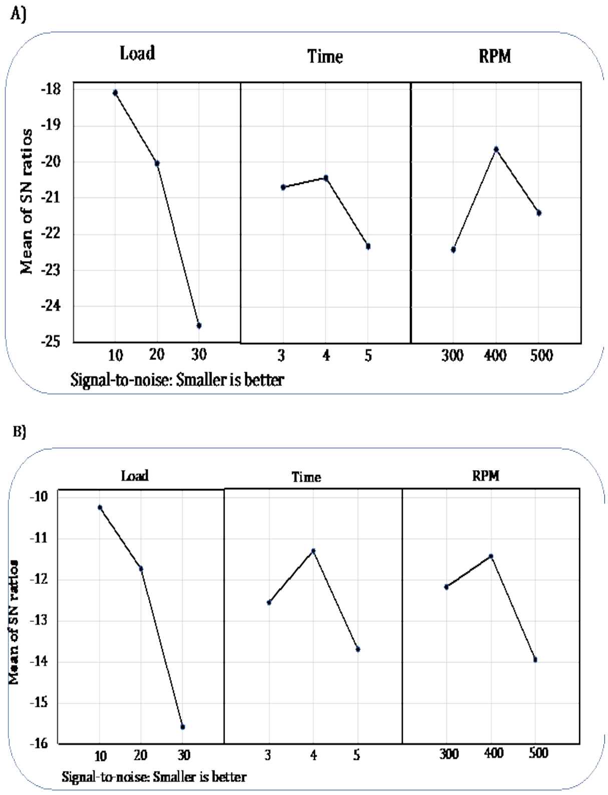

Fig. 4: Main effects plot for S/N Ratio for A) Wear and B) Friction force

The results indicate that all selected factors have nearly equal influence on the wear of the samples. Through Taguchi Analysis, it was determined that the optimal parameters for "optimal wear and friction force" are a load of 10 N, operating time of 4 minutes, and sliding speed of 400 rpm.

The Grey Relation Analysis (GRA) method is a tool for multi-objective function analysis. Here, the GRA has been used to confirm the findings of the Taguchi Analysis. The objective of this study is to identify the ideal composite structure wear and friction force parameter. The different values for different steps of GRA are shown below in Table 4.

Table 4. Normalised value, Deviation sequence and GR Coefficient of wear and frictional force.

	Normalised Value		**Deviation Sequences**		**GR Coefficient**	
S. N.	**Wear**	**F. F.**	**Wear**	**F. F.**	**Wear**	**F. F.**
1	7.6	3.1	0.93	0.92	0.06	0.08
2	6.8	2.7	1.00	1.00	0.00	0.00
3	10	4.1	0.74	0.72	0.26	0.28
4	9.3	3.2	0.80	0.90	0.20	0.10
5	9.0	3.9	0.82	0.76	0.18	0.24
6	16	4.6	0.24	0.62	0.75	0.38
7	18	7.7	0.08	0.00	0.92	1.00

8	19	4.7	0.00	0.50	1.00	0.40
9	14	6.0	0.41	0.34	0.59	0.66
Min	**6.8**	**2.7**	**Max: 1**	**1.00**	**Δ Max: 1**	**0.50**
Max	**19**	**7.7**	**Min: 0**	**0.00**	**Δ Min: 0**	**(Theta)**

The use of "Principal Component Analysis" (PCA) can be applied when utilizing "Grey Relational Analysis" (GRA) to solve problems with multiple performance characteristics to determine the weighting values for the different performance variables. The weighted value of each performance attribute has been determined and is displayed in Table 5 for all GR Grades that have been created using PCA.

Table 5. Calculation of Grey Relation Grade (GRG) using GR coefficient

S. N.	**GR Coefficient**		**Average**	
	Wear	**F. F.**	**GRG**	**Rank**
1	0.88	0.86	0.87	2
2	1.00	1.00	0.66	1
3	0.66	0.64	0.71	5
4	0.71	0.83	0.77	3
5	0.73	0.68	0.71	4
6	0.40	0.57	0.48	6
7	0.35	0.33	0.34	9
8	0.33	0.56	0.44	8
9	0.46	0.43	0.44	7

Knowing and unknowing elements are combined in GRA to generate optimal behaviour response values. The key quality elements are frictional force and wear. Based on the results of Grey Relational Analysis, the most favorable conditions for optimal wear and friction force are a load of 10 N, a time of operation of 4 minutes, and a sliding speed of 400 RPM.

4.0 Conclusion

India holds the position of the fifth-largest producer of citrus fruits globally. The country's significant citrus juice industry generates a substantial number of citrus peels as waste on an annual basis. The utilization of citrus waste as a low-cost renewable resource for developing composite materials is an attractive prospect, especially considering its inherent antibacterial and antioxidant activities. This research aims to optimize the wear behavior parameters, namely frictional force, and wear, of a composite material reinforced with particles derived from Citrus Limetta Peel, employing a Hybrid Taguchi-GRA-PCA methodology, which encompasses multi-step optimization tools. Initially, S/N (Signal-to-Noise) ratio values were computed for both performance factors during the analysis. Through Taguchi analysis, the optimal composite structure was identified, characterized by superior wear behavior with minimized wear and friction force. The optimal parameters for achieving desirable wear and friction force were determined as follows: a load of 10 N, a test time of 4 minutes, and a sliding speed of 400 RPM. The findings of the Grey Relation Analysis were consistent with those of the Taguchi Analysis, corroborating the identified optimal parameters. Consequently, it can be concluded that the most favorable composite structure, in terms of wear and friction force, is attained when subjected to a load of 10 N, a test time of 4 minutes, and a sliding speed of 400 RPM.

Based on the current study, the potential applications for composites fabricated from citrus Limetta peel encompass furniture and decorative items, doors, tables and shelves, and interior components of automobiles. These applications serve as a preliminary exploration of the composite's practical uses, while acknowledging the necessity for more extensive investigations that extend beyond the scope of the present manuscript.

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Nomenclature

GRA Grey Relation Analysis
PCA Principal Component Analysis
LVDT Linear Variable Differential Transformer
PP Polypropylene
LDPE Low Density Polyethylene
GRG Grey Relation Grades
GRC Grey Relation Coefficients
RPM Revolution per Minute

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