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Tribological and Physical Characterization of Citrus-Limetta Peel Reinforced Polyester Composites

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Abstract

Objective: To examine tribological properties of citrus-limetta peel reinforced polyester composites (CLPRPC) by varying weight fraction of citrus-limetta peel and testing parameters. Physical behavior is also studied for CLPRPC. Method/Analysis: CLPRPC was fabricated by varying weight fraction of peel in the range of 20%, 30% and 35 %. The testing was carried out using a pin-on-disc machine by changing the parameters as sliding distances, sliding speeds and applied load to study wear and friction behavior and also the empirical model is proposed for CLPRPC. The physical property is examined through the SEM (Scanning Electron Microscope). Findings: Citrus-limetta peel particles added to polymer composite for improving wear and friction properties. Tribological properties of CLPRPC seems batter than basic matrix composite. Analysis of variance (ANOVA) is performed on CLPRPC to know the effect of parameters on response. From ANOVA of CLPRPC disclosed that at 20 %, 30% and 35% weight fraction of CLPRPC, the highest influencing parameter for coefficient of friction is load, speed and load respectively, for wear is speed, sliding distance and sliding distance respectively. The regression equations also suggested to find wear and co-efficient of friction of CLPRPC and the worn-out surfaces are examined by Scanning Electron Microscopic (SEM).

Keywords: Citrus-limetta peel/polyester Composites, Wear & Friction, Pin on disc (POD), Mathematical Modeling, Taguchi approach, SEM (Scanning Electron Microscope).

INTRODUCTION

The acceptance and expansion in natural awareness toward the usage of unsustainable materials, encouraged thinking for the utilization of ecofriendly materials. Natural fibers are the ecofriendly materials which have great properties compared to synthetic fibers [1].The research carried out on industry show the fact that the industry sector concern with natural fiber reinforced polymer composites reached U$2.1 billion worldwide in 2010. Current scenario show that interest in natural fiber reinforced composites (NFPCs) industry around the world will grow quickly. An evaluation says that in last five years (2011–2016), the NFPCs industry is estimated to grow 10% worldwide [2].

Natural fibers in simple definition are fibers extract from plants or animals that are not synthetic or manmade [3]. The use of natural fiber such as jute, sisal, flax and oil palm for the production of composite materials, gets importance in the last decades, so far. The plants, which produce cellulose fibers can be classified into seed fibers (coir, kapok and cotton), bast fibers (hemp, kenaf, jute, flax and ranie), grass and reed fibers (corn, rice and wheat), core fibers (hemp, jute and kenaf), leaf fibers (pineapple, abaca and sisal) and all other kinds (wood and roots) [4]. The most widely recognized natural fibers in the world and world production have been shown in Table I.

Table I. Natural fibers in the world and their world production [4-5]

Fiber source	World production (10^3 tons)	Region
Cotton	18450	E, W
Jute	2300	W
Kenaf	970	E, W
Flax	830	UK, E, W
Sisal	378	W
Hemp	214	UK, E, W
Coir	100	W
Ramie	100	W
Abaca	70	W
Bamboo	10	W
UK = United Kingdom, W= Rest of the World, E = Europe.		

Application wise the use of NFPCs increases because of the superior advantages over synthetic fibers in terms of its biodegradability, processing flexibility, relatively low cost, low weight good relative mechanical properties, improved surface finish of molded parts composite [6].Adding of natural fiber into polymer (thermoplastic and thermoset) improve high specific stiffness and strength of NFPC [7].

On The other hand, the use of natural fibers as reinforce material is not easy because of having notable deficits in properties. The natural fibers permits moisture absorption form environment causes weaker bond between polymer and fiber and so mechanical properties may compromise. Making of composite is also challenging task due to various chemical structures of natural fibers and polymer. With the use of special treatments, the fiber modification is possible, which reduce absorption of moisture and give excellence bonding between fibers and polymer matrix [8].The demand of NFPCs in various engineering fields are growing rapidly. Some of the kind of NFPCs have replaced conventional materials for using in various automotive applications by many companies such as Cambridge industry (USA), Proton company (Malaysia) and German companies like BMW, Ford, Volkswagen etc. and recognized for that. Apart from automobile industry, the use of NFPCs have also been find out in sport, aerospace, building and construction, for example, bicycle frame, panels, decking and window frame [9].

LITERATURE REVIEW

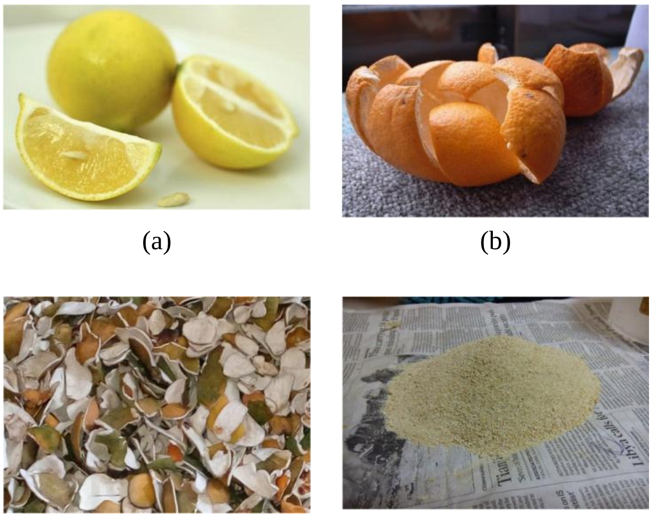
In 21st century, polymer have created good footprint over the usage in everyday life. To improve toughness of epoxy material, synthetic filler materials widely used as reinforcement. One of the suitable alternative to synthetic materials are using natural filler or fiber materials due to their renewability, cost effectiveness, environment friendliness and high abundance [10-19]. Lot of research have been done to study the tribological and mechanical behavior of natural filler or fiber based composites, concentrating mainly on filler or fibers and their volume or weight percent's within the composite [20-30]. Here, the study is concentrated on the tribological aspects by using the natural filler material as reinforcement in fabrication of composites. Citrus-limetta peel is selected as reinforcement due to easily available and eco-friendly behavior of it.

EXPERIMENTAL DETAILS

A. Materials

The citrus - limiter is one of the citrus organic product basically originated in Southeast Asia. Like all citrus natural products, the Citrus-limetta is acidic, having pH range 2.9-4.0. Citrus-limetta peel, the external cover of a Citrus-limetta, fundamentally comprises of proteins, cellulose, basic oils and some basic carbohydrates. The Citrus-limetta peels were collected from local market and the moisture was removed from the peels by applying sun drying technique for 5 days. The fibers were then crushed into a fine powder as shown in figure I.

Polyester resin used in the present investigation is AROPOL 7241 T-15 which is chemically belongs to ester family. It is supplied by Bansari Composite Pvt. Ltd., Anand. AROPOL 7241 T-15 resin is promoted, thixotropic, corrosion resistant isophthalic polyester resin. The resin has a high heat deflection temperature, high strength and has excellent corrosion resistance.



(a) (b) (c) (d)

Figure II. (a) Citrus-limetta; (b) Citrus-limetta peel; (C) Sun dried citrus-limetta peel; (d) citrus-limetta peel powder

B. Preparation of CLPRPC

A mould of dimension 300X300X10 mm^3 was used for preparing the composite sheet. A required amount of polyester resin, MEKP as a hardener (ratio of 10:1 by weight) and Cobalt as an accelerator mixed with citrus-limetta peel powder with providing gentle stirring to remove air entrapment during mixing. Then the mixture is poured into the mould placing on a miler sheet (wax coated.

To avoid the formation of air bubbles, special care was taken. Under the pressurized condition the mould was allowed to cure for 36 hours at room temperature. Care has been taken to consider the loss of some amount of polyester and hardener squeezes out during manufacturing under application of pressure so that a constant thickness of sample could be manufactured. This procedure was repeated for preparation of composites with 20, 30 and 35% weight fractions of citrus-limetta peel. After curing the composites were taken out of the mould and cut into long strips. Then the no. of pins were cut from long strips with the help of hand grinding cutter and machine to round shape with the help of hand grinding. They were further finished by fine glass paper to obtain fine surface finish. Then the pins are ready to perform on pin on disc machine.

Citrus-limetta composite sheet was cut to making the circular pin of diameter 10mm and length was 35mm.The pin was cut from sheet with the help of hand grinding machine to round shape will give by the block plane as shown in figure II.

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Figure IIII. Specimen pins of CLPRPC

C. Testing Methods

For finding the tribolgical properties of CLPRPC testing was completed on pin-on disc machine shown in figure III. In the design of experiment, the important stage lies in the choosing of the control factors. In this work Minitab 16 software used as a statistical tool and three levels for each three factors are selected as shown in Table II to construct a required orthogonal array for Taguchi experiments. With the use of Taguchi methodology, the experiment reduces to 9 runs instead of 3^3 = 27 runs required as per conventional full factorial design. As per L9 orthogonal array 9 experiments are required as shown in table III.

Figure III. Pin-on disc machine

Table II. Operating parameters

Parameter	**Level 1**	**Level 2**	**Level 3**
Load (kg)	2	3	4
Sliding Speed (rpm)	500	1000	1500
Sliding Distance (meter)	1000	1500	2000

Table III. Operating parameters

Sr. No.	**Load (kg)**	**Speed (rpm)**	**Sliding distance (mm)**
1	2	500	1000
2	2	1000	1500
3	2	1500	2000
4	3	500	1500
5	3	1000	2000
6	3	1500	1000
7	4	500	2000
8	4	1000	1000
9	4	1500	1500

RESULTS AND DISCUSSION

A. Effect of Operating Parameter on Wear

In sliding contacts, wear rate value continuously changing with duration of rubbing and also varies at different sliding velocities, sliding distance and normal loads. Wear for composite material tested under the conditions of, normal loads at 2, 3 and 4 (kg), sliding distance of 1000,1500 and 2000 (mm) and speed 500 ,1000and 1500 (rpm) for neat polyester, 20%, 30% and 35% weight fraction are shown in figure IV. The analyses are carried out by statistical tool.

Figure IV (a) shows the effect of normal load on wear for neat polyester, 20%, 30% and 35% weight fraction. For neat polyester and 20% w.f. graph shows that with increasing normal load wear will also increase up to 3 kg and then decrease at 4 kg. For 30% w.f. graph shows that with increasing normal load wear will decrease. For 35% w.f.it will increase with increasing normal loads.

Figure IV (b) shows the effect of sliding velocity on wear for neat polyester, 20%, 30% and 35% weight fraction. For neat polyester graph shows that wear will increase up to 1000 rpm and then decrease at 1500 rpm. For 20% and 30% w.f. graph shows that wear will decrease up to 1000 rpm and then increase at 1500 rpm. For 35% w.f.it will increase with increasing sliding velocity.

Figure IV (c) shows the effect of sliding distance on wear for neat polyester, 20%, 30% and 35% weight fraction. For neat polyester and 30% w.f. wear will decrease up to 1500 mm and then increase. For 20% and 35% w.f. graph shows that with increasing sliding distance wear will increase up to 1500 meter and then decrease.

The maximum wear was found for composite material for neat polyester at normal load of 3 kg, sliding velocity of 1000 rpm and sliding distance of 2000 mm. For 20% w.f. it will at normal load of 3 kg, sliding velocity of 500 rpm and sliding distance of 1500 mm. For 30% w.f. it will at normal load of 2 kg, sliding velocity of 1500 rpm and sliding distance of 2000 mm. For 35% w.f. it will at normal load of 4 kg, sliding velocity of 1500 rpm and sliding distance of 1500 mm. The minimum wear was found for composite material for neat polyester at normal load of 3 kg, sliding velocity of 1500 rpm and sliding distance of 1000 mm. For 20% w.f. it will at normal load of 4 kg, sliding velocity of 1000 rpm and sliding distance of 1000 mm. For 30% w.f. it will at normal load of 4 kg, sliding velocity of 1500 rpm and sliding distance of 1500 mm. For 35% w.f. it will at normal load of 4 kg, sliding velocity of 1000 rpm and sliding distance of 1000 mm.

Figure IV (d) show that weight fraction will give significant effect on wear of Composite material. For neat polyester it will high compare to others. Wear will decrease by neat, 30%, 35% and 20% respectively.

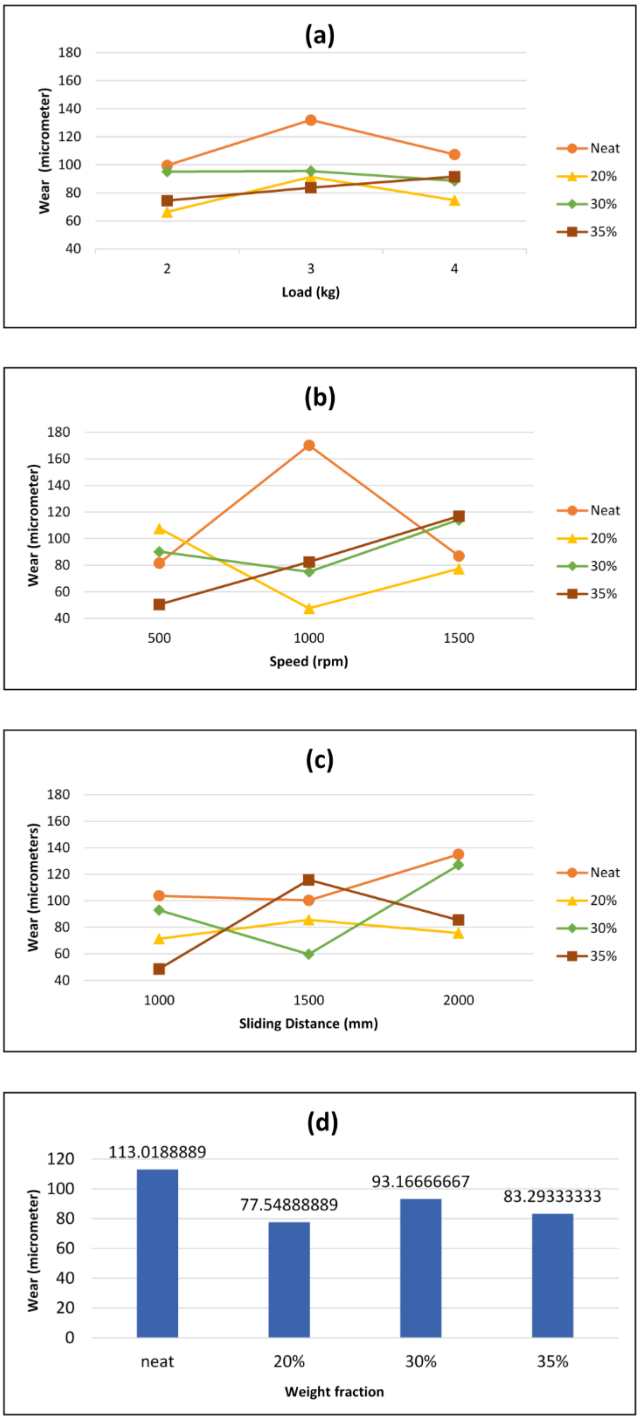

Figure IV. (a) Load v/s Wear (means); (b) Speed v/s Wear (means); (c) Sliding distance v/s Wear (means); (d) Weight fraction v/s Wear (means)

The regression equations were generated to find out wear shown in table IV for the 20%, 30% and 35% w.f. CLPRPC by considering the constrain of load from 2 to 4 kg, speed from 500 to 1500 rpm and sliding distance from 1000 to 2000 mm.

Table IV. Regression equations for finding wear of CLPRPC

Weight fraction of CLPRPC	Regression equation for finding Wear	Summary of Model
20%	W = 205.459 + 26.8415 (L) - 0.515558 (S) + 0.0797408 (SD) - 15.3119 (L*L) + 0.0637517 (S*L) + 0.000179613 (S*S) - 4.35183E-005 (S*SD)	S = 6.19109, R^2= 99.55%,
30%	W= 173.03 + 96.0267 (L) + 0.0356933 (S) - 0.377162 (SD) - 3.89667 (L*L) -0.0757967 (L*S) + 0.000107993 (S*S) + 0.000124577 (SD*SD)	S = 2.73118, R2= 99.94%,
35%	W = 288.132 - 342.749 (L) - 0.111757 (S) + 0.335598 (SD) + 26.2306 (L*L) + 0.167025 (L*S) - 0.000215245 (S*SD)	S = 8.19216, R2= 99.43%,

B. Effect of Operating Parameter on Co-efficient of Friction

In sliding contacts, friction coefficient value continuously changing with duration of rubbing and also varies at different sliding velocities, sliding distance and normal loads. Friction co-efficient for Composite Material tested under the conditions of, normal loads at 2, 3 and 4 (kg), sliding distance of 1000,1500 and 2000 (mm) and speed 500, 1000 and 1500 (rpm) for neat polyester, 20% w.f., 30% w.f. and 35% w.f. are shown in figure V. The analyses are carried out by statistical tool.

Figure V (a) shows the effect of normal load on friction co-efficient for neat polyester, 20% w.f., 30% w.f. and 35% w.f. For neat polyester and 35%w.f. graph shows that with increasing normal load, friction co-efficient will decrease up to 4 kg. For 20% w.f. graph shows that with increasing normal load, friction co-efficient will also increase. For 30% w.f. it will increase up to 3 kg and decrease at 4 kg.

Figure V (b) shows the effect of sliding velocity on friction co-efficient for neat polyester, 20% w.f., 30% w.f. and 35% w.f. For neat polyester graph shows that sliding velocity give dominant effect on friction co-efficient for material. This is increase up to 1000 rpm and friction co-efficient will decrease at 1500 rpm. For 20% w.f. graph shows that with decreasing sliding velocity up to 1000 rpm friction co-efficient will decrease and then increase at 1500 rpm. For 30% w.f. it will slightly decrease up to 1000 rpm and then also decrease at 1500 rpm. For 35% w.f. it will decrease up to 1500 rpm.

Figure V (c) shows the effect of sliding distance on friction co-efficient for neat polyester, 20% w.f., 30% w.f. and 35% w.f. For neat polyester graph shows that with increasing sliding distance friction co-efficient will increase up to 1500 mm and will decrease up to 2000 meter. For 20% w.f. graph shows that with increasing sliding distance friction co-efficient will increase up to 2000 meter. For 30% w.f. graph shows that with decreasing sliding velocity up to 1500 mm friction co-efficient will decrease and then increase at 2000 meter. For 35% w.f. will slightly decrease up to 2000 rpm.

Figure V (d) show that weight fraction will give significant effect on friction co-efficient of Composite materials. For 35% w.f. it will high compare to 20%, 30% and neat polyester. Friction co-efficient will increase by 20%, neat polyester, 30% and 35% respectively.

The regression equations were generated to find out co-efficient of friction shown in table V for the 20%, 30% and 35% w.f. CLPRPC by considering the constrain of load from 2 to 4 kg, speed from 500 to 1500 rpm and sliding distance from 1000 to 2000 mm.

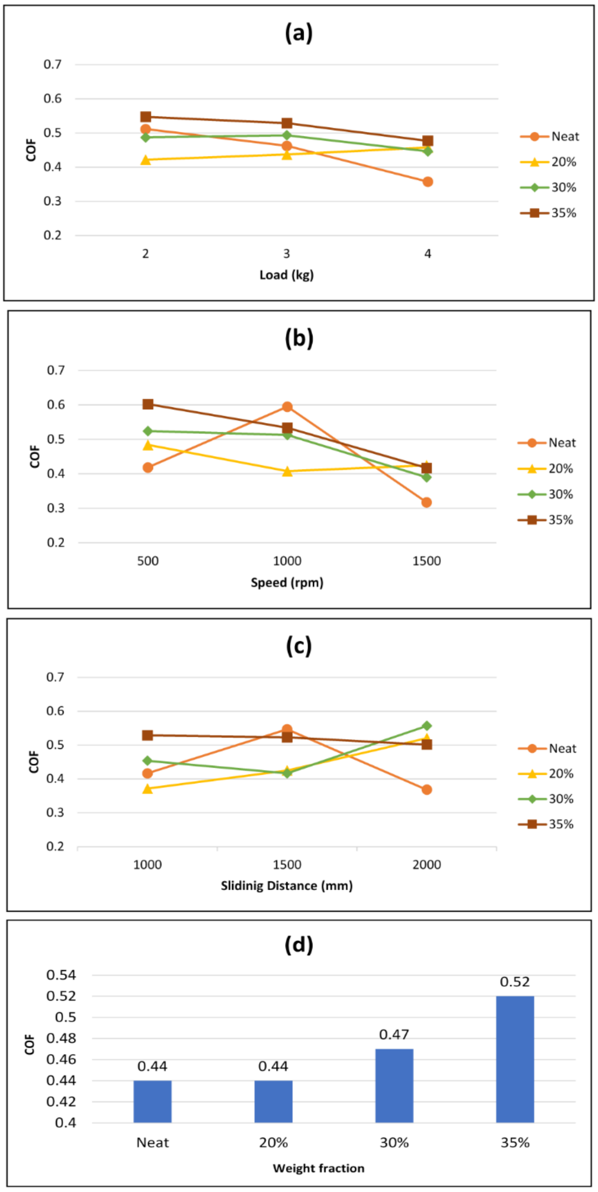

Figure V. (a) Load v/s COF (means); (b) Speed v/s COF (means); (c) Sliding distance v/s COF (means); (d) Weight fraction v/s COF (means)

Table V. Regression equations for finding Co-efficient of friction of CLPRPC

Weight fraction of CLPRPC	Regression equation for finding Wear	Summary of Model
20%	μ = 0.944417 - 0.243292 (L) + 0.000105667 (S) - 0.000454333 (SD) + 0.009875 (L*L) + 0.000127667 (SD*L) - 6.96667E-008 (SD*S) + 9.66667E-008(SD*SD)	S = 0.0208207, R2 = 99.22%,
30%	μ = 0.202667 + 0.306667 (L) + 0.000712333 (S) - 0.0005955 (SD) - 0.0333333 (L*L) - 0.000120333 (L*S) - 2.49333E-007 (S*S) + 2.08333E-007 (SD*SD)	S = 0.00122474, R2 = 100.00%,
35%	μ =1.84367 - 0.360667 (L) - 0.000840667 (S) - 0.000429619 (SD) + 0.000342 (L*S) - 2.57905E-007 (S*SD) - 3.2381E-005 (SD*L) + 3.09333E-007 (SD*SD)	S = 0.033638, R2= 98.88%,

PHYSICAL CHARACTERIZATION OF CLPRPC

The physical characterization was carried out by using SEM (Scanning electron microscope) of CLPRPC. The SEM analysis of worn surface was carried out for the sample of 20% weight fraction of citrus-limetta after the experiment of wear and friction as shown in figure VI. The sample was tested for load of 2 Kg, speed of 500 rpm and sliding distance of 1000 mm. It is observed through figure VI that the particles of Citrus-Limetta Peel is observed on the worn surface. The crack is also observed on the surface, it may be propagate through the particle and elongate over the surface due to the wear as shown in figure VI. The polyester back patch is observed due to the heating of surface.

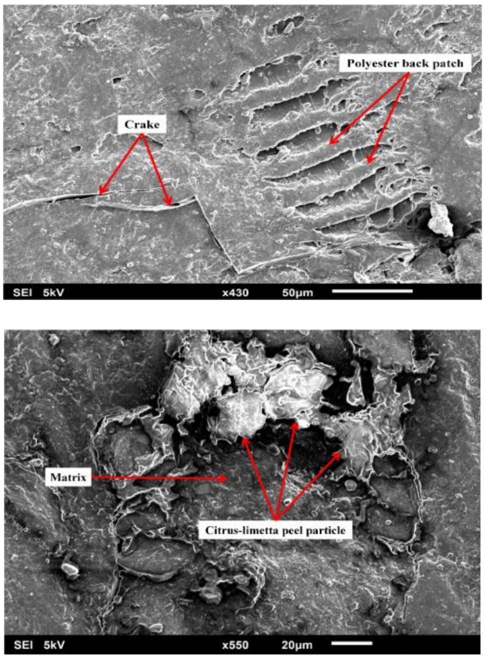

Figure VI. Physical behavior of warn surface of CLPRPC

CONCLUSION

The following significance outcomes were found from the study.

1. The co-efficient of friction is gradually increases with increase in weight fraction of CLPRPC, it may be happened due to the reinforcement particles at the contact surface of sample increases and generating more friction.
2. During rubbing the variation in wear of CLPRPC, depends on formation of thin polymer film during process. When polymer film formation start during rubbing it will decrease the wear resistance of composite material. At initial stage high frictional heat generated at the interface which leads to more polymer film come out which results of back transfer patches of polymer film in large extent which were recurrently spread over the surface. Hence, the wear is decreasing with increase in weight fraction of CLPRPC.
3. At 20 % weight fraction of CLPRPC, the most affecting parameter for coefficient of friction is load and for wear is speed. At 30 % weight fraction of CLPRPC, the most affecting parameter for coefficient of friction is speed and for wear is sliding distance. At 35 % weight fraction of CLPRPC, the most affecting parameter for coefficient of friction is load and for wear is sliding distance.
4. The R^2 values are in the range of 0.98 to 1 for co-efficient of friction and 0.994 to 0.995 for wear, which releves good accuracy of regression model proposed for wear and co-efficient of friction.

NOMENCLATURE

Parameters	Particulars	Units
W	Wear	Um
μ	Co-efficient of friction	-
SD	Sliding distance	M
L	Load	Kg
S	Speed	Rpm

REFERENCES

[1] May-Pat, A., Valadez-González, A. and Herrera-Franco, P.J., 2013. “Effect of fiber surface treatments on the essential work of fracture of HDPE-continuous henequen fiber-reinforced composites,” Polymer Testing, 32(6), pp.1114-1122.

[2] Uddin, N., Abro, A.M., Purdue, J.D. and Vaidya, U., 2013. Developments in fiber-reinforced polymer (FRP) composites for civil engineering: 13, Thermoplastic composites for bridge structures. Elsevier Inc. Chapters.

[3] Ticoalu, A., Aravinthan, T. and Cardona, F., 2010. “A review of current development in natural fiber composites for structural and infrastructure applications,” In Proceedings of the Southern Region Engineering Conference (SREC 2010) (pp. 113-117). Engineers Australia.

[4] Faruk, O., Bledzki, A.K., Fink, H.P. and Sain, M., 2012. “Biocomposites reinforced with natural fibers: 2000–2010,” Progress in polymer science, 37(11), pp.1552-1596.

[5] Staiger, M.P. and Tucker, N., 2008. “Natural-fibre composites in structural applications,” In Properties and performance of natural-fibre composites (pp. 269-300).

[6] Shalwan, A. and Yousif, B.F., 2013. “In state of art: mechanical and tribological behaviour of polymeric composites based on natural fibres,” Materials & Design, 48, pp.14-24.

[7] Xie, Y., Hill, C.A., Xiao, Z., Militz, H. and Mai, C., 2010. “Silane coupling agents used for natural fiber/polymer composites: A review,” Composites Part A: Applied Science and Manufacturing, 41(7), pp.806-819.

[8] Ray, S.S. and Bousmina, M., 2005. “Biodegradable polymers and their layered silicate nanocomposites: in greening the 21st century materials world,” Progress in materials science, 50(8), pp.962-1079.

[9] Shinoj, S., Visvanathan, R., Panigrahi, S. and Kochubabu, M., 2011. “Oil palm fiber (OPF) and its composites: A review,” Industrial Crops and Products, 33(1), pp.7-22.

[10] Parikh, H. H., & Gohil, P. P. (2015). “Composites as TRIBO materials in engineering systems: significance and applications,” In Processing Techniques and Tribological Behavior of Composite Materials (pp. 168-191). IGI Global.

[11] Chandramohan, D. and Marimuthu, K., 2011. “A review on natural fibers,” International Journal of Research and Reviews in Applied Sciences, 8(2), pp.194-206.

[12] Al-Oqla, F.M. and Sapuan, S.M., 2014. “Natural fiber reinforced polymer composites in industrial applications: feasibility of date palm fibers for sustainable automotive industry,” Journal of Cleaner Production, 66, pp.347-354.

[13] Ahmad, F., Choi, H.S. and Park, M.K., 2015. “A review: Natural fiber composites selection in view of mechanical, light weight, and economic properties,” Macromolecular materials and engineering, 300(1), pp.10-24.

[14] Gay, D., 2014. Composite materials: design and applications. CRC press.

[15] Pickering, K.L., Efendy, M.A. and Le, T.M., 2016. “A review of recent developments in natural fibre composites and their mechanical performance,” Composites Part A: Applied Science and Manufacturing, 83, pp.98-112.

[16] Al-Oqla, F.M., Sapuan, S.M., Anwer, T., Jawaid, M. and Hoque, M.E., 2015. "Natural fiber reinforced conductive polymer composites as functional materials: A review," Synthetic Metals, 206, pp.42-54.

[17] Atiqah, A., Maleque, M.A., Jawaid, M. and Iqbal, M., 2014. "Development of kenaf-glass reinforced unsaturated polyester hybrid composite for structural applications," Composites Part B: Engineering, 56, pp.68-73.

[18] Misnon, M.I., Islam, M.M., Epaarachchi, J.A. and Lau, K.T., 2014. "Potentiality of utilising natural textile materials for engineering composites applications," Materials & Design, 59, pp.359-368.

[19] Gurunathan, T., Mohanty, S. and Nayak, S.K., 2015. "A review of the recent developments in biocomposites based on natural fibres and their application perspectives," Composites Part A: Applied Science and Manufacturing, 77, pp.1-25.

[20] Gohil, P.P., Parikh, H.H. and Patel, V.B., 2014. "Investigations of Friction and Wear in Pultruded Glass Fibre Epoxy Composites," In Proceedings of International Conference on Advances in Tribology and Engineering Systems, Springer, New Delhi., pp. 181-193.

[21] Baria A., and Chokshi S., 2016. "Wear and Friction Behaviour of Corn Husk Fiber Reinforced Polyester Composites," International Journal for Scientific Research & Development, 4, pp. 803-806.

[22] Singh, N., Yousif, B.F. and Rilling, D., 2011. "Tribological characteristics of sustainable fiber-reinforced thermoplastic composites under wet adhesive wear," Tribology Transactions, 54(5), pp.736-748.

[23] Yousif, B.F., Lau, S.T. and McWilliam, S., 2010. "Polyester composite based on betelnut fibre for tribological applications," Tribology international, 43(1-2), pp.503-511.

[24] Rao, C.C., Madhusudan, S., Raghavendra, G. and Rao, E.V., 2012. "Investigation in to wear behavior of coir fiber reinforced epoxy composites with the Taguchi method," International Journal of Engineering Research and Applications (IJERA) ISSN, pp.2248-9622.

[25] Aireddy, H. and Mishra, S.C., 2011. "Tribological behavior and mechanical properties of Bio-waste reinforced polymer matrix composites," Journal of Metallurgy and Materials Science, Vol. 53 (2), pp. 139-152.

[26] Kranthi, G., Nayak, R., Biswas, S. and Satapathy, A., 2010. "Wear performance evaluation of pine wood dust filled epoxy composites," Proceedings of the International Conference on Advancements in Polymeric Materials.

[27] Ajay, G. and Navin, C., 2007. "Abrasive wear behaviour of bamboo powder filled polyester composite," bamboo composites, 7, pp.693-698.

[28] Nirmal, U., Hashim, J. and Low, K.O., 2012. "Adhesive wear and frictional performance of bamboo fibres reinforced epoxy composite," Tribology International, 47, pp.122-133.

[29] Chand, N. and Dwivedi, U.K., 2008. "Sliding wear and friction characteristics of sisal fibre reinforced polyester composites: Effect of silane coupling agent and applied load," Polymer Composites, 29(3), pp.280-284.

[30] Basavarajappa, S., Arun, K.V. and Davim, J.P., 2009. "Effect of filler materials on dry sliding wear behavior of polymer matrix composites–a Taguchi approach," Journal of Minerals and Materials Characterization and Engineering, 8(05), p.379.