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Wear Behaviour of PLA, ABS and Alumina Filled PLA Composite: A Comparative Study

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Abstract: ***Wear behaviour of 3D printed Poly Lactic Acid and fusion deposited alumina filled Poly Lactic Acid was investigated and compared to 3D printed Acrylonitrile Butadiene Styrene (ABS) with objectives for replacing petroleum-based polymers and their into automobiles. Since, petroleum-based polymer and their composites damage land, water and air causing natural resource depletion. This experiment was carried on the DUCOM TR-20LE (pin-on-disc) apparatus according to ASTM G99 standard under dry sliding condition that were carried out at room temperature. The load was varied 4.905 (N) to 34.335 (N) at speed of 500 RPM for the run time of 5 minutes. The results shown that applied load significantly affect explicit rate of wear, friction force, volume loss as well as frictional coefficient of specimens. According to the results of the experiment, alumina filled PLA specimens performed similarly to ABS specimens. This research will help to develop or replace petroleum-based polymers in a variety of applications.***

Keywords: PLA and ABS filament, PLA COMPOSITE (Al_2O_3), 3D Printing, Pin-on-disc

1. Introduction

Higher utilization of petroleum made fiber reinforced polymer compounds has resulted in an increase in environmental burden all around the world. For this reason, the development of both ecological and environmental reasons, the creation of bio- based composites has piqued the interest of material science. Bio- composites are both sustainable and biodegradable in nature. These materials contribute to a reduction in reliance on rapidly depleting petroleum supplies. Polylactic acid (PLA), fully bio-based polymer is obtained by fermenting corn, sugar beet potato, with several agricultural composites. Polylactic acid (PLA) possess excellent mechanical characteristics, exceptional barrier material capability and is easy to manufacture for a range of applications. Due to limitations like as extreme brittleness, water sensitivity and low impact strength, it must be altered for commercial use despite its enticing characteristics [1][2]. Addition of fillers is appropriate method for modifying & engineering mechanical, thermal as well as physical properties of PLA[3][4].

3D printing is the most common Additive Manufacturing (AM) technology, which use a computer-aided design (CAD) based on a three- dimensional model to produce any complex form, including material layer by layer[5]. The increasing use of 3D printing as a tool for education and the production of functional components has necessitated the creation of simulation solutions with designing considerations for professionals to understand better of mechanical behavior of 3D printed items. Fused It is believed to be a better option to other additive manufacturing processes because to its enhanced time, expense, benefits, and flexibility in creating complicated components or shapes with improved accuracy. [6]. The FDM technology often known as 3D printing will be used for the manufacturing of samples made by PLA and ABS filaments for the study of Tribological research in this project [7]. The phrase 3D printing machine refers to the process of depositing material along X,Y and Z axes. CNC based programming is used to achieve the control systems[8][9]. This enormous field of important tribo-engineering applications necessitate the study of Tribological characteristics like frictional force, coefficient of friction and wear of different kinds of Thermo-plastics along with other engineering properties. Materialistic characteristics of ABS & PLA .[10] given in table 1.

Table 1: Characteristics of ABS and PLA Polymers

Properties	PLA literature	PLA measured	ABS literature	ABS measured
Density	1.21 - 1.24	1.14 - 1.18	1.0 - 1.4	0.956 - 1.0
Melting point	170°C - 200°C	190°C - 200°C	200°C - 220°C	200°C
Biodegradable	YES	YES	NO	NO
Glass Transition Temperature	50°C-80°C	52°C	105°C	105°C
Flexural Modulus	4 Gpa	4 Gpa	2.1-7.6 Gpa	2.1-7.6 Gpa

Tribology is research of science bodies in relative motion that involves friction force, wear and lubrication. The experiment was carried out on the PIN-ON-DISC (DUCOM-TR20LE) instruments[11]. Friction and wear are reactions of a tribology system that are represented by coefficient of friction as well as friction force respectively. In reality it is hard to predict the coefficient of friction, friction force between the two bodies from material parameters and geometry. Since most of the materials may change their characteristics under coefficient of friction and frictional force[12].

Theoretically, the coefficient of friction is proportional with applied load. Through, this criterion is just satisfied by some polymers under specific conditions. Thus, it is difficult to generalize the results since it differ from polymer to polymer[13].

Thus, this study aims to investigate the coefficient of friction, frictional force, volume loss, specific wear rate of alumina filled PLA (Composite Materials) and compared with existing pure ABS material that was prepared using 3D printing machines.

It was found that performance of printed white ABS & PLA filaments was not significantly different. For ABS and PLA, full factorial Design of Experiment (DOE) is used to examine whole impact of optimal wear conditions produced by varying printing factors. Various sets of printing settings have been used to make ABS & PLA plastic samples.

The general formula of ABS$[(C_8H_8.C_4H_6.C_3H_3N)_n]$and PLA$[(C_3H_4O_2)_n]$.[14]

1.1 Objective

"In this project, an attempt is made to study the Tribological behaviour and physical characteristics of fabricated PLA and alumina filled PLA".

1.2 Outline of the project

"At present 60 to 70 % of plastic composites used in automotive parts are polypropylene, polyurethane, polyamides and PVC, these are based on petroleum polymers which are non-biodegrable and hazardous to environment".

2. Experimental Procedure

2.1 Sample preparation by 3D Printing:

Printed testing samples have been created using 3D printer that uses Fused Filament Fabrication (FFF), that is a widely utilised methodology, according to literature. Employed 3D printing model is, as shown in the Figure. The dimensions of specimen are 32mm in height and 12mm in diameter were printed using PLA and ABS filament. It operates at a temperature of initial stage of Pre-heat PLA and ABS filaments at a temperature around 30°C-40°C, in the material extrusion process or a heated chamber the PLA filaments melts at 190°C-200°C and ABS filaments melts at 210°C-220°C respectively.

It requires a power supply of 110 volt to 220 volt for the smooth operation of the 3D printers. It operates at a temperature of by stacking material on top of a digital model, it transforms it into a three-dimensional item by a heated nozzle. On the other side, the items are built directly onto the Platform. A blue print of the object is used to start the procedure. The 3D model is divided into thin, two-dimensional layers by printer-specific software. It then converts them to a set of machine language instructions that the printer can understand. To build a solid cylinder specimen of PLA and ABS filament, a print requires or takes a certain time to complete depending on the diameter, height, and size of the specimen to manufacture a solid cylinder specimen of PLA and ABS filament. It often involves the application of tape and other typical finishing touches. Getting the best surface polish. The geometry are drawn into solid works, also 3D CAD design file is further changed to slicing/personalization by exporting STL files, and the producing G-code for programming and initialising the information is then transferred to the printer to produce the parts. PLA and ABS filament were frequently used to print the specimens in the 3D printing machine.

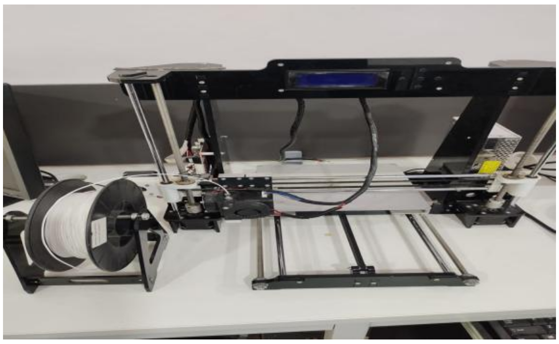

Figure 1: 3D Printing Machine

Table 2: Technical stipulations of 3D printer machine

Technology:	FFF (Fused Filament Fabrication)
Usable material:	PLA and ABS
Power supply:	110 -220 volt
Port:	2.0 SD card
Dimensions of printable area:	200x200x200 mm
Typical printing speed:	120 mm/s
Maximum printing speed:	150-300 mm/s (depending on the object to be printed)
Extrusion nozzle:	0.5mm
Aluminum profiles:	27.5x27.5mm
Movement:	3 stepping motors (NEMA)
Rated mechanical resolution:	X and y: 0.015mm,0.781µm
Nominal printing resolution:	Thickness (x,y):0.5 mm, Layer thickness: 0.2-0.25 mm)
Dimensions:	Width: 500 mm, Depth: 240mm, Height: 620mm
Weight:	9 Kg

2.2 Procedure for Preparing Composite Materials:

The following factors were considered when slicing PLA filament into little pieces. The use of fine alumina powder is 10% whereas PLA filament is used 90%.

The mixture of PLA filament and fine alumina powder by taking into a copper mould and heat treated at a temperature around 325°C to 350°C in the furnace.

At this temperature, PLA filament melts and then turns into a liquid state along with the fine alumina powder has linearly distributed. Then this mixture is poured into a copper cylinder mould shape and size having dimensions of 33mm height and a diameter of 12mm. By knocking them out the copper cylinder mould is cooled to room temperature. Finally, the specimens are prepared by using casting technique.

2.3 Tribological Behaviour Wear Testing on Pin-On-Disk:

Under order to measure and investigate tribological characteristics such as coefficient of friction & wearing in dry circumstances, DUCOMTR-20LE was used in conjunction with data program "winducom 2010." Samples material for wear test has been created by 3D printing machine and composite material having a dimension of 32mm in height and 12 mm in diameter. The ASTM G99 standard was used to conduct the wear test on a pin-on-disk at room temperature with dry sliding circumstances. Figure 2 depicts the pin-on-disc device's schematic. Acrylonitrile was used to remove rust and filth from degradation specimen as well as counter facing disc before they were subjected to the test conditions. Pin-on-disc spinning frictional force (N) and wear parameters of the produced samples/specimens are measured in (µm). Of both a stationary pin in the sample container and revolving disc, sliding occurs. It is possible to alter normal load, sliding speed, & wear track diameter to meet needs of test.

Figure 2: DUCOM-TR20 LE pin-on-disc set up

3. Measurements

(A) Theoretical Density (ρ_{th})

Theoretical density (ρ_{th}) of composite developed is deliberated by relationship amongst density and weight fraction

$$\frac{1}{\rho_{th}} = \frac{W_f}{\rho_f} + \frac{W_m}{\rho_m}$$

Where, Wm is matrix weight fraction, Wf is reinforcement weight fraction, ρf is reinforcement density and ρ_m is matrix density.

1.33 is the calculated value.

(B)Voids (V_{void})

The following relation was used to compute percent volume fraction in voids included in composites:

$$\frac{\rho_{th} - \rho_{th}}{\rho_{th}} \times 100\%$$

8% is the calculated value.

(C) Specific Gravity of Alumina Powder Al_2O_3 by pyconometer/ density bottle method

$$G_S = \frac{M_d}{M_d - (M_3 - M_4)}$$

Where, M_d is the mass of dry alumina powder (Al_2O_3), M_3 is the mass of pyconometer+Al_2O_3+ Distilled water (H_2O), M_4 is the mass of pyconometer+ Distilled water (H_2O).

3.9524 g/cc is calculated value.

(D) Coefficient of Friction (µ):
friction coefficient is ratio between the frictional force and the applied load.

Coefficient of Friction: $\mu = \frac{F_f}{F_n}$

Where, F_f is the frictional force (N) & F_n is normal loading

(E)VOLUME LOSS (CC): $\frac{W_1 - W_2}{\rho}$ OR $\frac{MASS\ LOSS}{DENSITY}$

(F) SPECIFIC WEAR RATE (SWR): $\frac{WEAR\ VOLUME}{SLIDING\ DISTANCE\ X\ APPLIED\ FORCE}$

4. Results and discussion

4.1 Specific Wear Rate (SWR):

Specific wear rate of alumina (Al_2O_3) content is more in comparison to Pure PLA samples and it is comparable with ABS samples as shown in fig 3. Further, specific wear rate grows with growth into load applied, for applied sliding speed of 2.62 m s-1. whereas, Alumina filled PLA shows lower fluctuation of SWR data within the range of 9.43x10-8mm^3/N mm to 1.30x10-7mm^3/Nmm and PLA shows a range of 8x10-7mm^3/N mm to 1.03x10-6mm^3/N mm as shown in Fig4. This indicates that wear performance by ABS and alumina filled PLA are comparable. It is anticipated that addition of fibers to alumina filled PLA shows better performance.

Table 3: Specific Wear Rate vs Applied load for PLA, ABS and Composite (PLA+Al_2O_3)

LOAD (N)	PURE PLA SWR (mm^3/Nmm)	COMPOSITE SWR (mm^3/Nmm)	PURE ABS SWR (mm^3/Nmm)
4.905	8.14E-07	_	1.56E-07
9.81	9.45E-07	_	1.30E-07
14.715	1.03E-06	9.43E-08	1.38E-07
19.62	1.01E-06	1.23E-07	1.30E-07
24.525	9.61E-07	1.42E-07	1.25E-07
29.43	1.03E-06	1.45E-07	1.12E-07
34.335	-	1.30E-07	1.19E-07

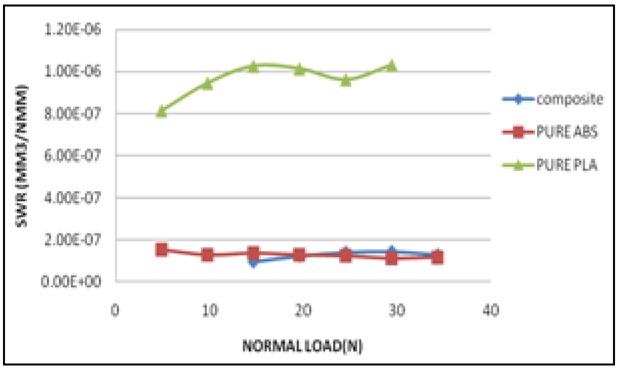

Figure 3: Specific Wear Rate vs Applied load for PLA, ABS and Composite (PLA+Al_2O_3)

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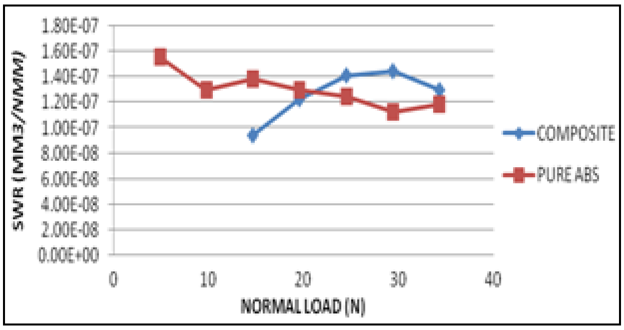

Figure 4: Comparsion of Specific Wear Rate vs Applied Load for PURE ABS and Composite (PLA+Al_2O_3)

4.2 Volume Loss (CC):

Increase in wear rate implies that volume loss grows with growth into normal loading applied, it can be observed that the slope of PLA sample for volume loss vs load is higher than ABS and alumina filled PLA. Whereas, slope ABS and alumina filled PLA slopes are comparable, as shown in Fig 5 and Fig 6.

Table 4: Volume Loss vs Applied load for PLA, ABS and Composite (PLA+Al_2O_3)

Load (N)	Pure PLA Volume Loss (CC)	Composite Volume Loss (CC)	Pure ABS Volume Loss (CC)
4.905	0.00313559	_	0.0006
9.81	0.007280702	_	0.001
14.715	0.01184874	0.001090343	0.0016
19.62	0.01561404	0.001892523	0.002
24.525	0.01850877	0.002725857	0.0024
29.43	0.023813	0.00334891	0.0026
34.335	-	0.003504673	0.0032

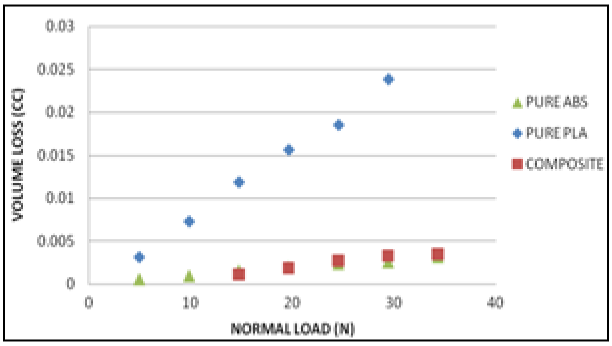

Figure 5: Volume Loss vs Applied load for PLA, ABS and Composite (PLA+Al_2O_3)

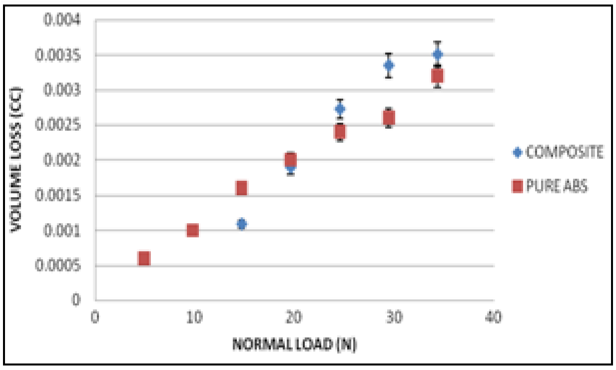

Figure 6: Comparison of Volume Loss vs Applied Load for PURE ABS and Composite (PLA+Al_2O_3)

4.3 Frictional Force (N)

Frictional Force was recorded periodically after every 300 sec and 500 rpm during the tribological testing for pure PLA and alumina filled PLA specimens. The frictional force was plotted for the different loads portrayed into fig7. Resistance shown by the bodies under sliding condition. Shows that, the alumina filled PLA composite specimens offer less frictional force as compared to pure ABS and pure PLA. The effect of frictional force on wear of engineering polymers is complicated as well as complicate outcome of macro as well as microscope response of surfaces move against each other (Kalkaska et al., 2012).

Shortly after testing began, it was discovered that friction force had attained a steady state value. For pure PLA at maximum load 29.43 (N) with constant speed or maximum speed 500 rpm it has been reached steady state whereas for composite and ABS at maximum load 34.335 (N) did portray high frictional force as of pure PLA.

Table 5: Shows Frictional Force (N) vs Applied load for PLA, ABS and Composite (PLA+Al_2O_3)

Load (N)	Pure PLA Frictional Force (N)	Composite Frictional Force (N)	Pure ABS Frictional Force (N)
4.905	0.7	_	0.5
9.81	1.3	_	1.5
14.715	2.4	1.2	2.2
19.62	3.6	2.2	3.6
24.525	4.9	3.4	4.2
29.43	5.2	5.2	5.3
34.335	-	5.4	5.4

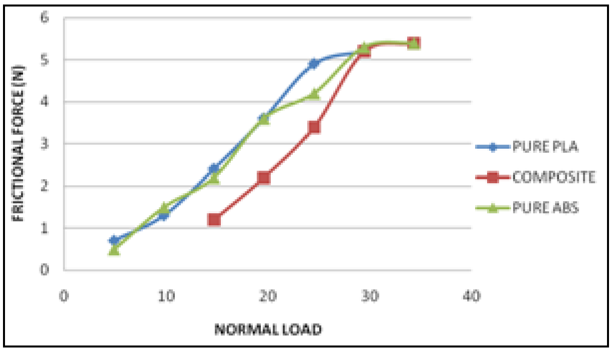

Figure 7: Frictional Force (N) vs Applied load for PLA, ABS and Composite (PLA+Al_2O_3)

4.4 Coefficient of Friction (μ)

Frictional coefficient is the proportion between frictional force with applied load.

The relationship amongst friction coefficient as well as run time / load applied under dry sliding condition is exhibited as shown in fig 8. The results shows that composite material had lesser coefficient of fraction as compared to pure PLA and ABS material. Impact of load applied as well as the run time upon frictional coefficient is varied, since it decreases from 4.905 to 9.81 N load then constantly increase from 14.715 to 34.335 N load for 5 min and 500 rpm, it shows the clear pattern cannot be seen for run time of 5min as the value of coefficient of fraction is fluctuated.

Table 6: Shows Coefficient of Friction (N) vs Applied load for PLA, ABS and Composite (PLA+Al_2O_3)

Load (N)	Pure PLA Coefficient Friction (µ)	Composite Coefficient Friction (µ)	Pure ABS Coefficient Friction (µ)
4.905	0.142712	-	0.101937
9.81	0.132518	-	0.152905
14.715	0.163099	0.081549	0.149507
19.62	0.183486	0.11213	0.183486
24.525	0.199796	0.138634	0.171254
29.43	0.17669	0.17669	0.180088
34.335	_	0.157274	0.157274

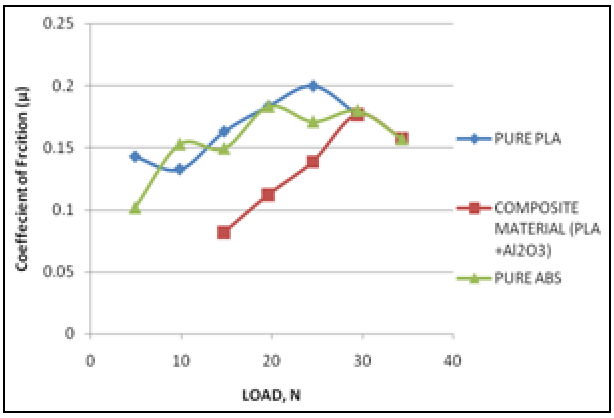

Figure 8: Coefficient of Friction (µ) vs Applied load (N) for PLA, ABS and Composite (PLA+Al_2O_3).

5. Conclusion

Alumina filled PLA shows comparable wear results with ABS. Based on the findings of this investigation, the following observations may be drawn:

- PLA shows 8% to 10 % of void space when calculated using theoretical density of PLA
- Volume loss is significantly higher than the ABS and PLA composite.
- Friction force reaches steady state at load of 30N at speed of 500rpm when tested for 5 minutes.
- Overall, it can be concluded that addition of 10% Al_2O_3 significantly increases wear performance of PLA.
- The results motivates for further investigation on PLA based composites as substitute material for petroleum based engineering plastics.

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